CHEMISTRY
OF THE
FARM AND HOME

TOTTINGHAM AND INCE

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THE FARM AND HOME

BY

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PREFACE

In recent years, coincident with the development of secondary schools of agriculture, there seems to have developed a tendency for teachers and authors to dismember the subject of chemistry. To a greater or less extent this subject has been appropriated for use in treating such subjects as soils, agronomy, and animal and dairy husbandries. Such treatment, where carried to an excess, is surely to be deplored. In the future, as in the past, the basic sciences, chemistry and physics, will be the great sources of principles which guide the practice of agriculture. This is necessarily the case on account of the leading importance of these sciences in the broader field of physiology, a subject which deals with the mechanism and behavior of the two great centers of interest in agricultural pursuits, namely the plant and the animal.

Fortunately, it is still recognized as important that, coincident with their instruction in art and practice, the students of agricultural high schools and secondary schools of agriculture shall be instructed in the elements of physics and chemistry. There has been, also, considerable demand for a textbook which would present in elementary form the whole field of the application of chemistry to agriculture. Too many of even college texts in this field have been poorly balanced, expanding to considerable length the treatment of some subjects, such as the soil or the plant, and yet inadequately covering the equally important subject of animal nutrition and its related topics. An elementary textbook in this field seems likely to be especially important for students completing their education in the high school or secondary school. This book presents sufficient general chemistry in the first five chapters to serve as a foundation for the study of the succeeding chapters, which are of applied character. The authors have tried to make the text both informational and stimulative of independent thinking.

The summaries of the chapters will be helpful for review and for selecting quiz topics. The experiments should prove most useful, as laboratory methods are most conducive of abiding knowledge. The material allows for the selection of the most useful experiments under varying conditions. The contents of the appendix will be of further assistance to the teacher.

The following acknowledgments should be made:

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CHAPTER I

GENERAL INTRODUCTION

Definition of Chemistry. Chemistry is the science which deals with the composition of *matter* and the molecular changes which it undergoes.

Descriptive chemistry treats of the natural character of different substances, their properties, uses, and their manipulation in the laboratory.

Theoretical chemistry endeavors to explain the facts of chemical phenomena by advancing *theories* and discovering *laws* to show the relation of the facts.

Definition of Other Terms. A science is the organized knowledge of a particular subject. The following are examples: chemistry, physics, botany, physiology, zoology, and geology. Botany is the science of plants; zoology, of animals; geology, of the earth and its evolution. All these sciences deal with various forms of matter. Chemistry, therefore, must be closely associated with these other sciences.

A fact is a truth. It may be known or unknown; but, of course, in science we are limited to truths which have been experienced and proved. Facts, or truths, do not change; but in the evolution of a science the acceptance of imperfectly known truth for fact must necessarily be supplanted by further experience and experiment. Science grows.

A law is a rule which expresses the manner in which substances have been observed to react.

An hypothesis is a supposition without proof which may result in the discovery of a law.

A theory is an hypothesis offered in explanation of the phenomena of nature and which has a certain amount of scientific demonstration to substantiate it. The acquisition of new facts may result in the revision or rejection of a theory.

Matter is anything which occupies space. It also has weight. There are thousands of different kinds of matter, existing either in the form of a solid or a liquid or a gas, such as iron, water, and air. We distinguish between substances, or kinds of matter, by their characteristics or qualities, which, in chemistry, are called *properties*. Is it solid, liquid, or gas? Is it lighter or heavier than water? What are its color and odor? Does it burn? Is it soluble in water? These are some of the questions which refer to the properties of matter.

Energy may be defined as the capacity for performing work. In other words, it is a *force* or *power*. Anything that produces motion or tends to change motion is called a *force*. Matter, under the influence of a force, can, therefore, do work upon other matter, and is said to "possess energy." Some examples of the manifestation of energy are heat, light, wind, life processes, and chemical affinity, or energy. The measure of the work performed by motion is the product of the force by the distance through which the force acts.

Chemical energy is that force which reacts between different substances in such a way as to disintegrate and reform into new compounds. In the change energy is developed. Chemical energy may produce light, heat, electricity, etc., or these, in turn, may produce chemical energy. Electricity and light may result from the chemical change in a battery. Electricity passed through oxygen and hydrogen causes an explosive chemical change that creates the compound water.

Conservation of Matter and Energy. In all physical and chemical changes alike there is no loss or gain of matter or force. Action is always equal to reaction, and the weights before and after chemical results constitute an equation. Matter is indestructible and "the sum total of the energy of the universe is a fixed unalterable quantity."

Importance of Chemistry. Chemistry has almost endless practical bearing on everyday life. We are living beings. What are the secrets of life's processes? We breathe the air. What is its function? We drink water and eat foods. We must. Why? How do they become assimilated and manifest their energy? We build houses out of wood or stone and mortar and glass. All these materials are the products of chemical processes.

Medicine, sanitation, and domestic science make extended use of chemistry. The important manufacturing processes of iron and steel, illuminating gas, paints, soap, paper, fertilizers, etc., all depend upon chemical principles for their discovery and greatest efficiency. A knowledge of chemistry is also necessary for the intelligent study of the other natural sciences.

And chemistry cannot be excluded from the farm. Practically the whole subject of fertilizers and soil conditions and productivity is in the domain of this science. The growth of the crop, the diseases that may attack it, insecticides and fungicides, successful feeding of stock, the keeping of milk, and the making of butter and cheese all abound in chemical reactions. To the chemist is due a large share of the advance in scientific farming.

The intimate relationship between chemistry and agriculture may be likened to that of a hub and a wheel. Using this comparison, Figure 1 graphically illustrates some of the principal features in which chemistry has been of service to agriculture.

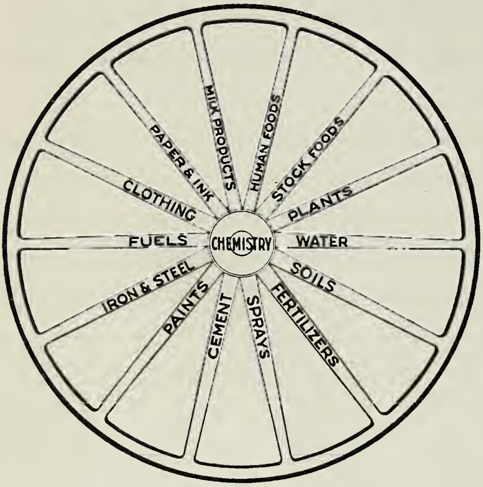


Figure 1.—The relationship of chemistry and agriculture.

Chemistry is an exact and unalterable science. Its principles operate whether we know and believe them or not. They do not accommodate themselves to us. We must put ourselves in harmony with them. It behooves us, therefore, to study and understand them. We are sure of success, if we have nature on our side. We are sure to fail, if it is against us.

Civilized man has enlarged his life by giving bodily existence to the secrets of chemistry which he has discovered. He is constantly inventing new substances which minister to his need. The savage, however, in his ignorance is content with his primitive hut and fire. The study of chemistry, then, stimulates the imagination and contributes to the advancement of civilization.

Elements and Compounds. There are many thousand different kinds of matter. Some of these substances are very familiar to everybody, for example, iron, salt, and water. Other substances are more or less common, as muriatic acid, while hundreds of others are extremely rare and only known as museum specimens or those secured by some investigator in his studies. These great quantities of different materials consist of one, two or more different kinds of matter. Those that it is impossible by any known means to decompose or divide into simpler forms of matter, differing from the original substances, are elementary and are called *elements.* For example, pure iron cannot be decomposed by any known means, into parts differing from iron. Iron is an element. Those substances that are formed by the chemical union of two or more elements are called *compounds.* A compound may be broken up by chemical means into the elements of which it is composed. But a compound cannot be decomposed by mere mechanical subdivision into its elements. For example, sulphur and iron may form a compound by a chemical reaction. This compound may be decomposed by chemical means into the original substances, iron and sulphur. But the compound cannot be separated by simple mechanical processes into iron and sulphur.

At present there are about eighty elements known to chemists. There are at least two hundred thousand compounds which have actually been prepared and studied. Many more are theoretically possible. In Table I is given a list of two dozen elements which are of special interest in connection with the study of everyday life. A complete list of all the elements is given in the Appendix.

TABLE I—A Selected List of 24 Chemical Elements and Their Symbols

Element	Symbol	Element	Symbol
Aluminium	Al	Mercury	Hg
Argon	A	Nickel	Ni
Arsenic	As	Nitrogen	N
Calcium	Ca	Oxygen	O
Carbon	C	Phosphorus	P
Chlorine	Cl	Potassium	K
Copper	Cu	Silicon	Si
Gold	Au	Silver	Ag
Hydrogen	H	Sodium	Na
Iron	Fe	Sulphur	S
Lead	Pb	Tin	Sn
Magnesium	Mg	Zinc	Zn

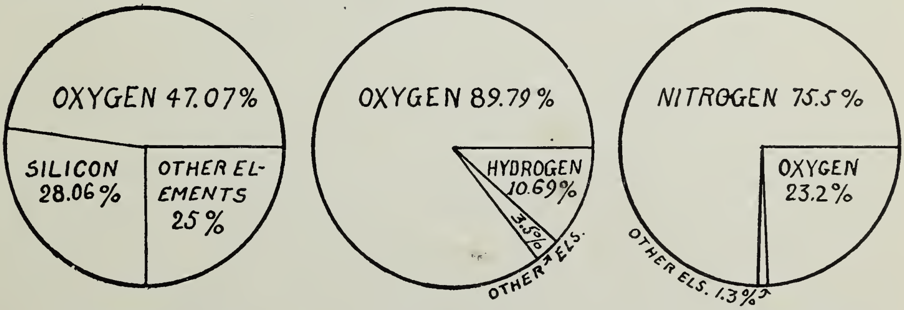
Compounds and Mixtures. It is necessary to distinguish carefully between the two expressions, *compound* and *mixture.* As already stated, a compound is formed by the chemical union of elements. But a mixture is formed by merely intermingling two or more substances, without chemical union. The constituents of a compound cannot be separated by a mere mechanical process; but the components of a mixture can be separated in this manner. For example, a mixture of iron filings and sulphur powder may be entirely separated by using a sieve of the proper fineness. There are two other general differences between compounds and mixtures. First, in a compound the elements are united in definite proportions; in a mixture the ingredients may be present in any proportion. Second, when a compound is formed, there is usually some change of energy, as the liberation of light or heat; when a mixture is prepared, there is usually no such change of energy. The number of mixtures possible is, of course, infinite. Mixtures are very common and familiar. The soil is a mixture of a large number of minerals. The rock, granite, is a mixture of a number of minerals such as quartz, mica, feldspar, and hornblende. Milk is a mixture of water, fat, sugar, and proteins, with some mineral matter.

Abundance of Elements. There are about 80 elements which exist in nature. It is interesting to note the relative predominance of these substances. Of the above number there are only eight elements, each one of which exists in the whole terrestrial globe to an extent of one per cent or over by weight. Less than half of all the elements are ever found free. Less than half are common, and many are very rare.

It has been estimated that the surface layer of the earth, to a depth of ten miles, consists of approximately 93% solid crust and 7% water. The atmosphere is about 0.03% of the total. With these figures as a basis, and knowing the kind and amount of the different substances present in the surface layer mentioned, it is possible to compute the relative amount of the different elements quite accurately. Beyond the ten mile depth it would be possible only to speculate as to the composition of the earth materials. Over 99% of the matter of our planet is made up of only thirteen of the elements, united in various compounds. The other elements exist in relatively small quantities.

TABLE II—Average Composition of the Terrestrial Globe

	Per cent of solid crust (93%)	Per cent of ocean (7%)	Average, including atmosphere (100%)
Oxygen	47.07	85.79	49.78
Silicon	28.06	.....	26.08
Aluminium	7.90	.....	7.34
Iron	4.43	.....	4.11
Calcium	3.44	.05	3.19
Magnesium	2.40	.14	2.24
Sodium	2.43	1.14	2.33
Potassium	2.45	.04	2.28
Hydrogen	.22	10.67	.95
Carbon	.20	.002	.19
Chlorine	.07	2.07	.21
Phosphorus	.11	.....	.11
Sulphur	.11	.09	.11
Nitrogen	.....	.....	.02
All other elements	1.11	.008	1.06
	100.00	100.00	100.00



THE EARTH THE OCEAN THE ATMOSPHERE

Figure 2.—The relative abundance of the elements.

Figure 2 contains three simple diagrams which show the relative abundance of the elements in the earth's crust, the ocean, and the atmosphere. What is the most striking feature illustrated by this series of diagrams?

Chemistry and Physics. The statement was made in the opening paragraph of the chapter that chemistry is concerned with the study of matter and the changes which matter may undergo. There is another science which is also involved in such studies, but from a different point of view. That science is *physics*. *Chemistry* is primarily interested in the study of matter, what it is composed of, its characteristics, and the products into which it may be converted by certain agencies or forces. *Physics*, on the other hand, is principally concerned with the subject of energy and its transformations. The difference in the field of these two sciences may be expressed in the following manner. Physics considers especially the changes in which the composition of the substance is not altered, while chemistry considers those changes that result in new substances. It is true that a certain change in matter may interest both the chemist and the physicist inasmuch as energy may be consumed or produced by this phenomenon. In fact, there is a comparatively new science, physical chemistry, which involves both chemistry and physics.

Physical and Chemical Changes. Matter may undergo a great many changes, some natural and some artificial. The change of water to ice and the rusting of iron take place under certain natural conditions. The smelting of copper ores and the burning of fuel are artificial conditions. It is easy to tell that there has been a change in each of these cases, because the properties of the substances obtained are different from those of the substances taken. All changes are divided into two classes, physical and chemical. Physical changes are those in which the composition of the substance is not affected. It is possible to repeat a physical change with the same substance. Examples of such changes are the melting of ice and the production of light from incandescent electric lamps. Chemical changes are those in which the composition of the substance is involved. Examples of such changes are the burning of coal and the rusting of iron.

Physical and Chemical Properties. In describing different kinds of matter and the results of their changes we make use of the properties of these materials. For purposes of convenience the properties are classed as either physical or chemical. The physical properties are

1. Form or state; as gas, liquid, or solid. This varies with conditions of temperature and pressure.
2. Weight or specific gravity. This is the weight relative to some determined standard
3. Color, odor, and taste.
4. Electrical characteristics.

These properties can be determined without any reaction or chemical change.

The chemical properties are

1. The ability to combine with other elements or compounds, and the manner in which the combination takes place.
    a. Active, readily uniting.
    b. Inactive, not readily uniting.
    c. Active with certain elements and under certain conditions; inactive with other elements and under other conditions.
2. The products formed as the result of reactions.

These properties can be shown only by a chemical change.

The agricultural scene shown in Figure 3 illustrates a number of applications of the points that have been under discussion in this chapter. The traction engine uses oil, a form of matter. By the process of combustion the oil is converted into other products, but in doing so a large amount of heat is liberated. Heat embodies energy and is capable of doing work. The engine is able, then, to proceed through the field and drag the gang plows or other implements after it. What kind of change takes place in the combustion

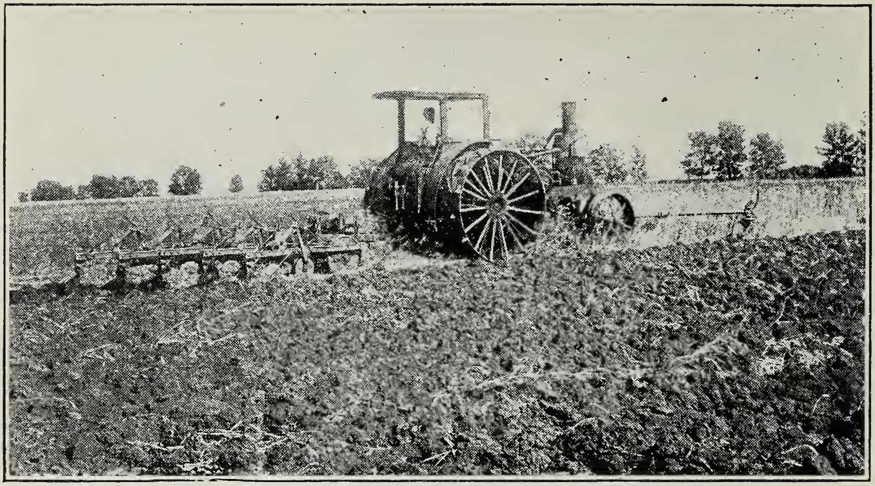


Figure 3.—An agricultural application of chemistry.

chambers of the engine? What kind of change does the plow effect in the soil? What kind of change does the exposure of fresh portions of the soil to the air bring about? These and other questions naturally suggest themselves to the student.

SUMMARY

The science of chemistry treats of matter and the changes which matter undergoes. It is made up of a collection of facts, laws, and theories concerning thousands of different substances and phenomena and the effect of different forms of energy. Chemistry is a subject of great interest and importance. Its principles are in application in our everyday life, in many manufacturing processes, and in other sciences. It is especially of practical benefit in the study of scientific agriculture.

There are about eighty elements of which only twenty-four are common in our daily life. There are thousands of compounds, some of which occur in nature, others being purely artificial. The elements are very unequally distributed. Only nine occur to the extent of one per cent or over of the earth.

Several sciences are closely associated with chemistry. There is usually, though, some more or less definite line separating the field of those overlapping subjects. For example, both physics and chemistry deal with matter and the changes of matter induced by energy. But, while chemistry takes up those changes that result in new substances, physics considers especially the changes in which the composition of the substance is not altered, but wherein energy is concerned. In other words, chemistry concerns matter and physics concerns energy.

QUESTIONS

1. Define science, fact, theory.
2. Distinguish between the meaning of the following pairs of terms: matter and energy; element and compound; compound and mixture; physical change and chemical change.
3. Give two examples of chemical change (not previously mentioned) and show how it can be proved that they are chemical changes.
4. Classify the following as physical or chemical changes: the rusting of iron, the souring of milk, the melting of ice, the drying of paint, the corrosion of metals, the magnetization of steel.
5. Give a list of properties by which matter may be recognized.
6. What properties could you make use of to distinguish between salt and sugar?
7. Why should everyone know something about the science of Chemistry?
8. If there are other sciences, just what is the particular field of Chemistry?
9. What is the essential difference in the scope of the two sciences, Chemistry and Physics.

CHAPTER II

WATER AND ITS CONSTITUENT ELEMENTS

WATER

Introduction. *Water* is of the greatest importance to mankind. It is one of the most abundant chemical compounds and has taken an active part in the formation of the earth's surface. Climatic conditions are modified by the presence of water. It is one of the controlling factors of plant life and animals cannot exist without it. Certain industries depend upon water for their successful operation. It is a valuable source of power both for generating steam and as waterfalls. On account of these facts and because water is already more or less familiar to the student, we will begin our study of chemistry with a consideration of this substance.

Distribution. Water occurs free in nature in large bodies, such as oceans, lakes, and rivers, which cover about eight elevenths of the surface of the earth. It is also distributed in the form of smaller bodies like rivulets, springs, brooks and underground sources. It is also present in soils. Water is one of the most important constituents of the atmosphere. It may be present there either as invisible vapor or as clouds and fogs, which are really aggregates of minute drops of liquid water.

From 50 to 90 per cent, or on an average about three fourths, of the weight of living matter, both plant and animal, is water. In these instances water may be present as circulating water of vegetation, or sap, and as the chief constituent of the animal body fluids; also in the combined form mentioned below. The amount of moisture present varies widely in the limits indicated. There is given in

Table III a list of a few typical vegetable and animal products and their content of water.

Table III.—Amount of Water in Certain Natural Products

	Per Cent		Per Cent
Green red clover hay	70	Milk	85
Cucumbers	96	Blood	80
Potatoes	78	Trout	78
Wood	50	Fat pig	41
Turnip	90	Lean pig	55
Fruits	80	Jelly fishes	99.5

In addition to the free water held by the living cells, the elements of which water is composed, hydrogen and oxygen, are combined with the other elements which enter into the composition of plant and animal bodies. When such substances are heated, they are usually decomposed. If the products of decomposition are collected, water can be proved to be present.

Almost all vegetable matter in the finely cut condition or even when uncut, contains a certain amount of moisture, called hygroscopic moisture, which it has absorbed from the atmosphere. The amount of this moisture varies with climatic conditions, such as the amount of moisture in the air and the temperature.

Many mineral substances contain large quantities of water combined in their structure. This may very easily be shown by heating some clay or rock powder or epsom salts in a test tube. Water is liberated and condenses in drops on the cooler portion of the glass. In many cases the presence of this water is responsible for the characteristic crystalline shape and other properties of the material. Blue vitriol, copper sulphate, for example, is ordinarily a crystalline blue solid. Alum is an octahedron, an eight-sided crystal, which has the appearance of two pyramids with their bases placed together. Both of these substances, when heated to a high temperature, lose the water which is combined with them, and become white powders.

It is necessary to note in this connection that all crystalline compounds do not contain water of crystallization. Salt and sugar are the most common examples of such exceptions. Any water found in common salt is either held there mechanically between the crystals or else is moisture absorbed from the atmosphere.

Figure 4 shows graphically the amount of water and solids, such as starch and other constituents, in the potato. This may be regarded as a fairly typical illustration of the distribution of water in the plant kingdom.

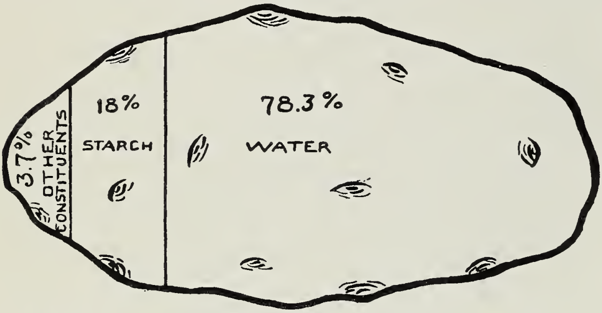


Figure 4.—Graphic representation of the composition of a potato.

Kinds of Water. *Pure water*, as will be shown, is a compound of two elements, hydrogen and oxygen. In the pure form it practically never occurs in nature. Natural waters contain impurities which differ considerably in character. Some of these foreign matters are visible to the eye and are merely suspended in the water, such as algae, vegetable matter, and dust. Other impurities are invisible and dissolved in the water, such as gases and salts. The nature of these suspended and dissolved materials is very different, depending upon the conditions through which the water has passed. Some of the principal factors affecting the composition of water are (1) substances present in the air, (2) the character of rocks and soils over which the water has coursed, and (3) the opportunities the water has had of losing material previously gathered, as by settling or oxidation. Hence the character of any given natural water is dependent mainly upon the part of the natural circuit at which the sample of water in question is taken.

Rain water is the purest water that can be found in nature, because it is condensed water vapor. Yet rain contains some impurities gathered from the atmosphere. The first portions of a rainfall dissolve certain gases and wash the dust particles down to the earth. After it has rained for a time, the most of these gaseous impurities have been removed from the air. Consequently the later rainfall is fairly free from the substances. On the other hand all natural waters contain nitrogen, oxygen and carbon dioxide dissolved in them. These are not to be regarded as impurities from the hygienic sense, but they are, of course, impurities in the strictly chemical sense. They give taste and zest to the water. Most persons notice the difference of flavor between boiled water and fresh water. It is the presence of the dissolved oxygen in the fresh water which makes the difference.

Soil water contains those substances which are easily dissolved by rain. These soluble materials may be taken up by plants and utilized by them in their growth or they may drain off into rivers or ground waters.

Spring water may contain a considerable amount and often a great variety of dissolved minerals. These also are derived from the rocks and soil through which the water has filtered. Such water usually contains a large amount of gases which are liberated as soon as the water reaches the surface of the ground. One of these gases, carbon dioxide, partly increases the solvent action of the rain upon the rock material. In this way large quantities of limestone are found in solution where limestone predominates in the earth's crust. The great advantage of spring water is its purity from disease germs and organic matter.

River water contains materials both in solution and in suspension which it has secured from soil and rocks and the atmosphere. Rivers are merely large currents of spring water. The springs feed a river by either pouring into its current from the banks or else helping to swell the tributary streams. The river water has absorbed some of its impurities by its contact with the surface of the earth and by the smaller streams that pour into it. This indicates that river water is not as pure as spring water. It is, on the other hand, very soft as compared with spring water and is, therefore, more healthful, if it is free from disease germs.

Sea water and *salt lakes* contain the most impurities of any natural water. The rivers are constantly bringing to the ocean new supplies of salts dissolved from the land. The oceans, therefore, are the great storehouses of all natural salts. Hardly a substance can be named which is not found to a certain extent in sea water. Attempts have been made to extract even the gold that is present in these waters. The extremely small quantities of this valuable metal, however, present a great difficulty in recovery.

A convenient classification for natural waters is given below. This shows in condensed form the differences in the amount and character of the impurities of water.

Atmospheric	Rain—some gases, very little dissolved solids.
	Snow—dust, etc.
	Fog—some gases, dirt and dust.
Terrestrial, Fresh	Surface—cloudy, small amount of dissolved material, large amount of suspended material.
	Underground—clear, large amount of dissolved material, small amount of suspended material.
Terrestrial, Salt	Brines—over 5% soluble salts.
	Sea water—3.6% soluble salts.
Terrestrial, Mineral	Excess of dissolved gases and mineral matter.

Circulation of Water. There is a constant circulation of water in nature. This so-called *cycle* can be represented by a diagram (see Figure 5) where the different stages are indicated at different positions upon a circle. By evaporation from large bodies of water and soils, by the transpiration of plants, and the respiration of animals water passes into the atmosphere in the form of a vapor. Under certain conditions this vapor condenses, forming clouds and fogs, and returns to the earth's surface in the form of rain. Moisture may also be precipitated from the atmosphere in the form of snow, sleet, hail, dew and frost. From the surface of the earth the water may go in any of three directions. First, it runs off directly downward over the land into brooks and rivers. This is surface drainage and is sometimes called the *run-off*. Second, part is retained as the ground water of soils and part sinks deeply into subterranean supplies of water. This is underground drainage and is called the *cut-off*. Such waters often come to the surface again through natural fissures, as mineral springs, or by artificial openings as in the case of wells. Third, a portion may pass up from the land by evaporation into the atmosphere. This has been called the *fly-off*. The rivers flow into the oceans and from there the cycle may start again, being constantly repeated. Certain portions of water need not necessarily pass through all the stages of the circuit as indicated above. Some, for example, may continually pass and repass between land and atmosphere without ever finding its way into the ocean; the most of the moisture evaporated from the ocean and condensed as rain returns to the ocean through rivers; and some may be diverted to salt lakes. This ceaseless round continues as long as the sun furnishes the needed energy. Thus all water power is really derived from the sun.

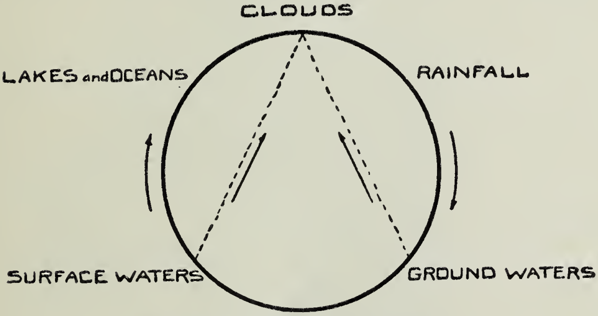


Figure 5.—The cycle of water.

Purification of Water. As has been already indicated, practically all natural waters are more or less impure. The materials which may be present are either solid substances in suspension, or gases and solids in solution. In order to purify the water for drinking or for industrial and household uses, these materials must be removed. There are a number of methods which can be used for this purpose, but the choice of method depends upon the character of the water and the use to which it is to be put. Simple filtration of water may be sufficient to remove solid impurities. This may be accomplished by a charcoal filter, by a sand filter, or by a layer of any other material, which will serve to aerate the water and remove the bacteria, dirt and other suspended foreign matter present. Quite a few examples of such *mechanical filters* are found in the household and in the large city water-filtration plants.

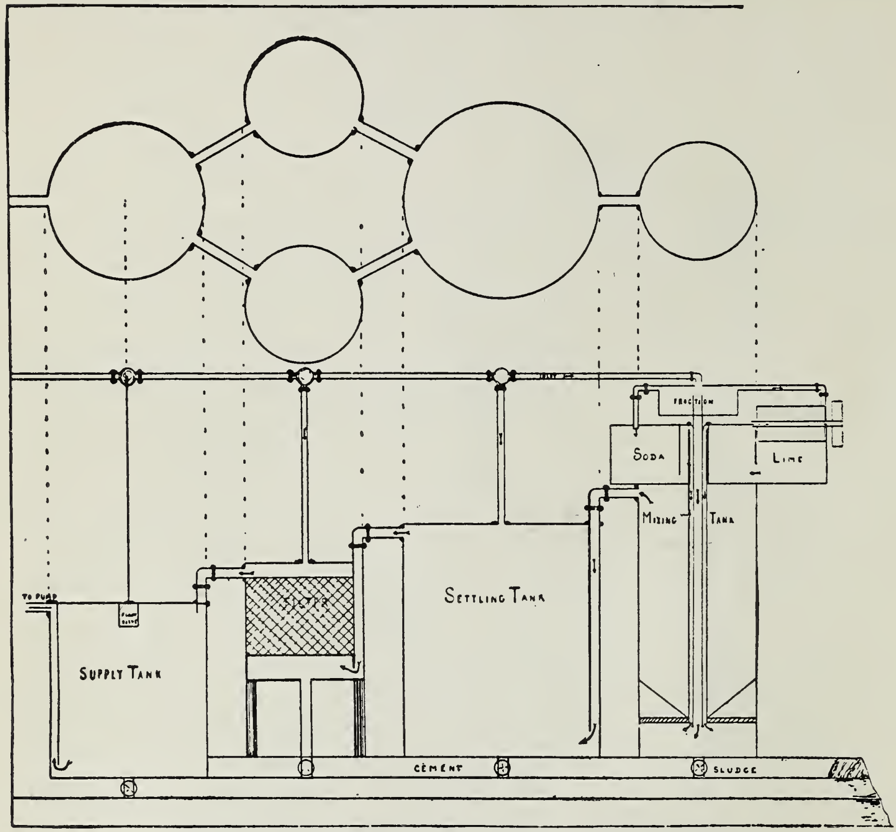


Figure 6.—Cross-section of a water purification plant.

Boiling may accomplish a partial purification of the water by expelling gases in solution, killing bacteria, and causing such substances as limestone to be precipitated from the solution. The addition of chemicals, such as milk of lime, alum, and sulphate of iron, may also partially purify water for both household and industrial uses by precipitating the limestone and other impurities which are dissolved in the water. A cross-section of a commercia- plant used for this pure pose is shown in Figur- 6. Distillation, however, is the only methl od for producing water which is practically pure and free from all foreign matter. The general term distillation applies to a process in which a liquid is heated and changed to a vapor, which in turn is cooled and condensed to a liquid. Figure 7 shows a laboratory still. In the case of water, the first portions (about one-fifth) of the condensed liquid can be discarded, since they contain some of the gaseous impurities of the original water. Also the last portion (1/5) of the original quantity which contains all the salts is left in the still. The distillate that comes over between these portions is the pure water which is desired.

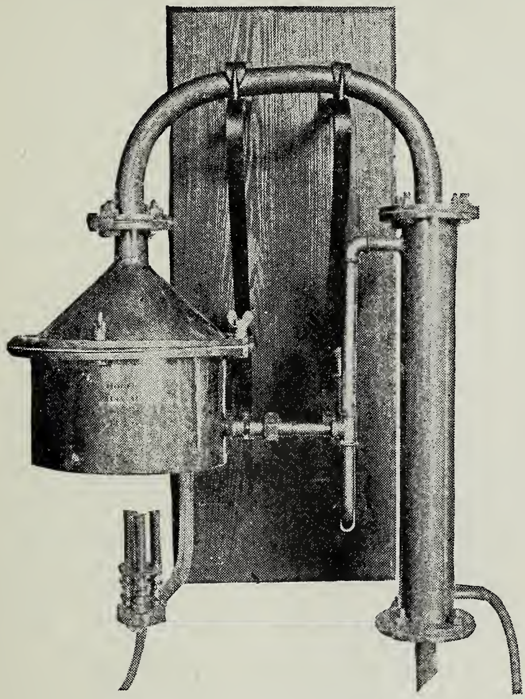


Figure 7. A laboratory still.

River water may gather considerable organic impurities as it passes over its course. In this refuse material of plant and animal origin there may be some micro-organisms. Some of these may be the common bacteria characteristic of sewage, for example, or manure piles, or even of certain diseases. If the river is sluggish, these impurities are not removed readily. But, if the river has a swift current and especially if there are rapids and waterfalls in its course, the water soon purifies itself by bringing its impurities into contact with the oxygen of the air, which destroys them. The sewage of Chicago is emptied into the Illinois river. After flowing 300 miles, this empties into the Mississippi a few miles above the point from which St. Louis takes its water supply. This seems to be a dangerous procedure, but it has been proved that this water has no more bacteria than neighboring rivers which do not receive sewage. In addition to the oxidation already mentioned, it is possible that the bacteria consume the sewage very quickly and then die for lack of food. They may also be devoured by other organisms or killed by the sunlight.

Physical Properties. Water, when pure, is an odorless and tasteless liquid, colorless in small masses but pale greenish blue when seen in considerable thickness. In this respect it is quite similar to an ordinary window pane of glass. It is a poor conductor of heat and electricity. Water dissolves many solids, liquids, and gases. It is in fact the most common solvent known.

Water is probably the most familiar example of a substance that can exist in three states of matter without change of composition. It is a gas, commonly called steam, above 100°C., a liquid, water, between 0° and 100°C., and a solid, ice, below 0°C. In its passage from one state to another, considerable heat may be liberated or absorbed as the case may be. In passing into the gaseous state, a gram of water absorbs 537 calories* and expands from

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*A calorie is the quantity of heat necessary to raise 1 gram of water from 0° to 1°C.

1 to 1,728 volumes. In other words, a cubic inch of water will make a cubic foot of steam. Water will, however, become a vapor at all temperatures depending upon whether the surrounding atmosphere is saturated or not. In the liquid form water is practically incompressible, a property which is of use in the well known *hydraulic press.* But when a gram of liquid water becomes ice, it expands 10% and liberates 79 calories. This phenomenon is responsible for a great many burst water pipes, the splitting of rocks, and the heaving effect of frost in the ground. Because water expands in freezing, ice is lighter than water and floats.

Water is used as a standard of weight, 1 cubic centimeter at 4°C. being called 1 gram. The boiling point and freezing point of water are used as convenient points for standardizing thermometer scales; on the Centigrade, 100° and 0° respectively; on the Fahrenheit 212° and 32°. As a standard unit of specific gravity measurements, water serves both for solids and liquids. The hydrometer floats at 1 in distilled water of 15.5°C. On the Baumé scale water is marked at 0.

Solution. The importance of water as an agent for dissolving different kinds of matter is very apparent. In the discussion of the cycle of water, reference has been made to this action. We will now consider briefly a few general points in connection with the character of solution. The substances concerned are mixed in such a way that the matter of each is distributed uniformly through that of the others. The expression *homogeneous mixture* can be used to designate this condition, that is, every part of the mixture is composed of the same kind and quantity of matter. If this term were considered broadly, it might include a large number of phenomena, but it is usually restricted to the absorption of a gas, a liquid, or solid, within the space occupied by some liquid. The liquid is called the *solvent.* The dissolved material is called the *solute.* The most common solvent is water, though alcohol and ether are also common, especially in drug preparations. Water dissolves nearly all substances to an appreciable extent. The permanent tissues of plants and animals, India rubber, resins and some other substances are practically insoluble.

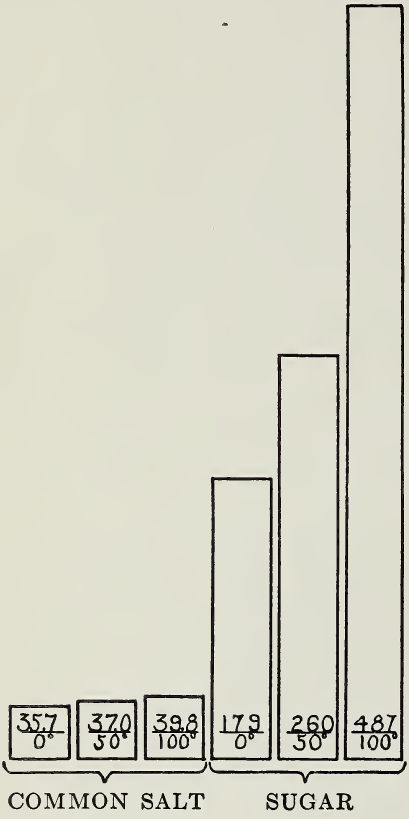

Figure 8.—The solubility of salt and sugar.

Soluble and *insoluble* are merely relative terms, since there is probably no substance of which a small amount will not dissolve, if the quantity of the solvent is large enough. Generally speaking, *readily soluble* is applied to a substance that requires less than 100 times its weight for complete solution; *difficultly soluble,* between 100 and 1,000 times; and *insoluble,* when more than 1,000 parts of the solvent are required.

The term *solubility,* when applied to a substance, means the maximum amount of that material that can be taken up by a given quantity of the solvent under the given conditions. The student is probably already aware that substances differ greatly in their degree of solubility. He also knows that temperature has a decided influence upon the amount of a substance that can be dissolved. As a rule, the higher the temperature, the greater the amount of solids dissolved, but the less the amount of gases.

A comparison of two household articles illustrates these points in connection with the varying solubility of chemical materials. Common salt is nearly as soluble in cold water as in hot. Sugar, on the other hand, is much more soluble than salt and increases in solubility very strikingly as the temperature is raised. Figure 8 very clearly shows such differences in solubility. The figures indicate the number of grams of material dissolved in 100 cubic centimeters of water at the temperatures given on the Centigrade scale.

The specific gravity of solutions of solids is greater than that of the solvent. Substances in solution raise the boiling point and lower the freezing point of the solvent. When small quantities of substances are dissolved in a solvent, there is apparently no increase of volume. There is usually an evolution of heat and increase of temperature when a gas dissolves in a liquid. But the solution of a solid is usually attended by an absorption of heat and a reduction of temperature, though there are certain exceptions.

The solubility of gases depends not only upon temperature but also upon pressure. Generally an increase of temperature means a decrease of the quantity of gas dissolved, though there are exceptions to this rule. An increase of pressure increases the solubility of gases. Carbonated waters of the soda fountain are the most common example, where a large amount of gas has been forced into water and kept there under pressure. When the stopper is removed from the bottle, there is a rapid escape of the gas on account of the reduced pressure. Certain natural waters exhibit the same characteristic.

The solubility of gases varies, depending upon the character of the gas. Some are only very slightly soluble while others are exceptionally so. For example, 100 volumes of water at 0°C., dissolve only 5 volumes of oxygen, but nearly 115,000 volumes of ammonia.

Chemical Properties. Water is a very stable substance; in other words it does not decompose readily. Although it can be decomposed into its elements by heat alone, it requires a very high temperature. At 2,500°C., for example, only about 5% of the entire amount is decomposed. It is possible to break up water into its constituent elements by the electric current and by some chemical methods.

Electrolysis, which means a tearing apart by means of electricity, is the simplest method and the one most easily demonstrated for decomposing water. This method, moreover, has the advantage of showing some facts in relation to the composition of water. The process is carried out as follows: A current from an electric battery is passed between platinum electrodes through water containing about 5% of its weight of sulphuric acid. While the current is passing, bubbles of gas rise from the electrodes up through the liquid. The gases may be collected separately by inverting over each electrode a tube filled with the dilute acid. The rates at which the two gases collect are not the same. The one at the negative electrode collects a little more than twice as rapidly as the other. The former is called *hydrogen* and the latter is called *oxygen*. Figure 9 shows the nature of the apparatus used to demonstrate the electrolysis of water.

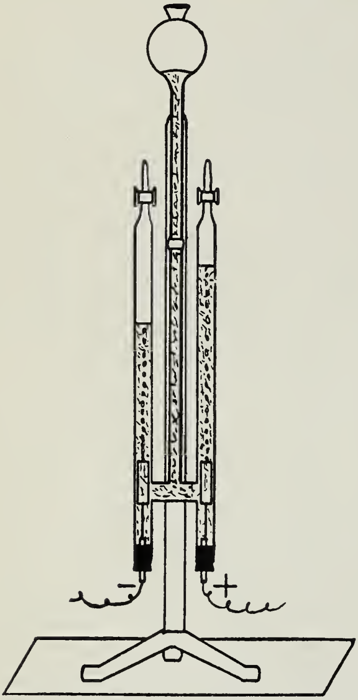

Figure 9—The electrolysis of water.

The relation between the volume of the two gases is really two parts hydrogen and one part oxygen. The ratio is generally slightly larger on account of several errors, one being that the oxygen is more soluble in the liquid than is the hydrogen. Water itself is a poor conductor of electricity and is not electrolyzed. The purpose of adding the sulphuric acid is to serve as a carrier for the electricity. The water, however, is the substance which is actually decomposed by the process.

From the electrolysis of water, therefore, two substances are obtained that are gases at ordinary conditions. They are different from water in their properties and different from each other. One is a gas which burns, but does not support combustion. The other is a gas which supports combustion, but does not burn. The first is called *hydrogen*, because, when it burns, water is formed. The word hydrogen comes from two Greek words meaning "to generate water." The other gas is called *oxygen*, meaning "acid producer," also derived from the Greek. These will be studied more in detail after the subject of water.

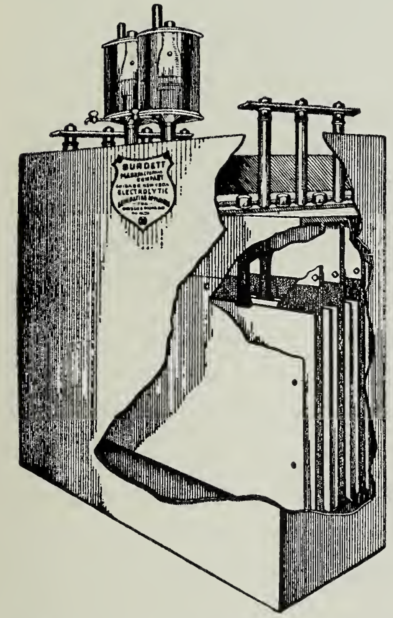

Figure 10.—An electrolytic cell for decomposing water.

That the electrolysis of water is an important commercial process is shown by the fact that this operation is carried on at the present time upon an enormous scale. Figure 10 illustrates the cross section view of one type of an electrolytic cell and Figure 11 shows a battery of these cells used for generating large quantities of oxygen and hydrogen.

Action of Metals. Water may also be decomposed by coming in contact with certain metals. Cold water reacts directly with a metal called potassium. A gas is liberated which proves to be the same as one of those from the electrolysis of water. The potassium disappears in

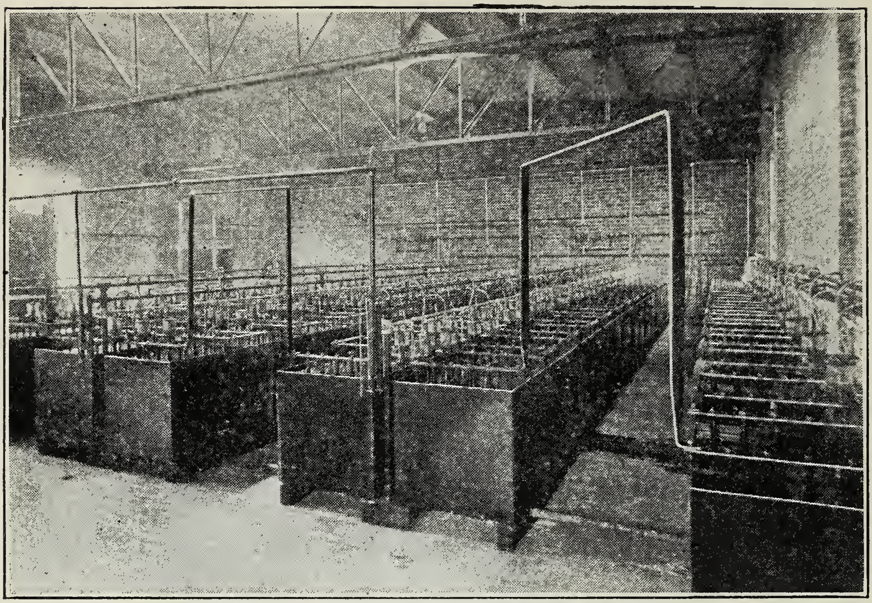

Figure 11.—A battery of electrolytic cells for the commercial production of hydrogen and oxygen.

the reaction and the liquid entirely changes its properties. It is now soapy to the touch, has a bitter taste, and turns red litmus paper blue. Another metal, sodium, acts in the same way as potassium. The intensity of the reaction is not so great. Two other metals, lithium and magnesium decompose hot water and red hot iron decomposes steam. The reaction, therefore, can take place with several metals, if the temperature of the water or the condition of the water is changed to conform to the particular metal used.

These experiments may be carried on in such a manner that the gas given off from the reacting materials can be collected in a proper manner and its properties learned. If a small piece of sodium, for example, is placed at the mouth of a test tube full of water inverted in a beaker of water, the sodium at once rises to the top of the tube and commences to react with the liquid. That a gas is given off, is at once apparent; for the volume of water is pushed out of the tube in proportion to the amount of the metal taken in the experiment. After the reaction is completed, the tube and its contents of water and gas can be removed from the beaker by placing the thumb over the opening of the tube. The tube is inverted into its normal condition and a lighted match is held to the mouth. The gas either burns or a slight explosion results from the admixture of the air. In this way, it can be proved that the gas is the same as that liberated in the greatest quantity by the electrolysis of water. In other words it is hydrogen.

Action of Chlorine. Certain other substances decompose water, liberating the other constituent, which we have already found by electrolysis. This may readily be shown by filling a long tube, closed at one end, with a strong solution of chlorine in water. Invert the tube in a glass containing the same solution and place the whole apparatus in bright sunlight. Bubbles of a gas will soon rise and collect in the tube. It can be proved that this gas is oxygen, by holding a glowing splinter of wood at the mouth of the tube, after sufficient gas is collected for a test. The chlorine has a more powerful attraction for the hydrogen of the water than the oxygen has, hence chlorine combines with the hydrogen and liberates the oxygen. The principle of this reaction is very important and will be referred to again under the head of bleaching. Fluorine, an element which is similar to chlorine but even more active than chlorine, has the same effect upon water.

Water as a Chemical Agent. As a chemical agent, water is extremely powerful, acting usually as a solvent but in many cases producing profound changes of a chemical character. Many anhydrous substances combine with water, when crystallizing. The water so added is called *water of hydration* or *water of crystallization.* The presence of the water in the structure of these compounds entirely changes their properties. Copper sulphate, when anhydrous (that is, without water), is a yellowish white powder. One drop of water changes this immediately to a pale blue color. Alum, when anhydrous, does not give its characteristic taste when applied to the tongue. One drop of water instantly restores the peculiar effect of that compound upon the tongue. Quicklime, when slaked with water, combines directly with it, giving off considerable heat and forming milk of lime. These are examples of the direct chemical union of water with other substances.

Water assists as a solvent in many chemical actions. Two solids may be in contact with each other and no reaction take place. Yet a small amount of water may quickly cause a reaction between the two materials. Baking powder and Seidlitz powders are familiar examples of this fact. The same statement holds true, moreover, of gaseous as well as solid mixtures. The presence of moisture seems to be one of the conditions essential to the reaction of substances in the gaseous state. For this reason solutions of solids in water are more frequently employed in chemistry than the solids themselves. Water is, therefore, very useful in the chemical laboratory.

Water seems to aid in another way in bringing about certain reactions. The ordinary *rusting* of iron which takes place under the usual conditions of that action is an example. It is a well known fact that, if tools, machinery and other implements are kept in a dry shed or coated with oil to keep off the atmospheric moisture and rain, they do not rust. Iron is plated with tin, zinc, or nickel for that reason, to cover the iron and prevent its rusting. The same point is true also of the rotting of wood. Under ordinary conditions, wood cannot rot if dry. Moisture aids bacteria in attacking wood. We paint our houses and dip our fence posts in tar or creosote or zinc chloride to keep out water or to impregnate the woody fiber with compounds that will prevent bacterial action.

When combined with substances like carbon dioxide, sulphur dioxide and other atmospheric gases, water becomes a very active agent in decomposing rocks and soils. This subject will be more completely discussed in the chapter upon soils.

Usefulness in Nature. Water in the course of its cycle has effected great changes in the earth's surface. By the mechanical process of erosion and transportation of rock material, by the physical solution of soil material, and by chemical action upon soils and rocks, it has changed the distribution of the solid matter of the globe.

Water vapor is the most variable constituent of the atmosphere and the most important from a geological point of view. It not only dissolves and disintegrates rocks and soils, but it also acts as a carrier for other substances, distributing them and making them more active. For example, the rainfall dissolves and concentrates other ingredients of the atmosphere and brings them to the ground. At least two of these substances, oxygen and carbon dioxide, are of the greatest importance, since they serve to bring about in the earth's surface changes that vitally affect all life processes. Without the aid of water, their effectiveness would be very small. Certain other constituents of the air as ammonia gas and sulphur dioxide are brought to earth by water vapor. The quantities of these gases dissolved and distributed are small and variable, but they affect plant life and are important to note in this connection.

As has been already indicated the downward flow of water from the land surface into rivers and oceans is a part of the great circulation of water. In this manner water dissolves from rocks and soils considerable mineral matter and also carries much solid material in suspension. This action on the part of water is commonly called *erosion* and is exceedingly important in bringing about certain results. Erosion is partly mechanical and partly chemical and the two actions re-enforce each other. By flowing streams rocks are ground to sand and new surfaces are exposed to chemical attack. Then chemical solution weakens the rocks and renders them easier to wear away mechanically. According to an estimate the total annual rainfall upon all the land of the globe amounts to 29,347 cubic miles. Of this, 6,524 cubic miles drain off through rivers to the sea. A cubic mile of river water weighs 4,205,650,000 tons approximately and carries in solution, on the average, 762,587 tons of foreign matter. In all nearly five billion tons of solid substances are thus carried annually to the ocean. These figures give some idea of the extent of the chemical work which the percolating waters are doing. Taking the Mississippi river as an example, it has been estimated that, if all the material which this river carries in solution into the Gulf of Mexico yearly were collected in one big mass, it would make a pile of solid matter covering one square mile to a height of ninety feet. If the sediment which is carried in suspension were added to this pile, it would add another 241 feet of solid matter.

Climatic Effects. Water has powerfully affected climates. The gulf stream helps to make the British Isles habitable for men. Without this warm current their climate would approximate that of Labrador. Other portions of the globe are influenced in a like manner by the oceanic circulation. On account of the high specific heat of water large bodies of water tend to equalize the temperature of adjacent land.

The atmospheric circulation of water has also an equalizing influence. The vast amount of water changed to vapor from the surface of oceans in warm climates absorbs an immense amount of heat. This heat is again liberated when the vapor condenses to rain or snow in colder regions. Atmospheric vapor, moreover, acts as a sort of blanket over the earth's surface, helping to retain the warmth of the latter. The effect of fogs, mists and clouds in keeping off frosts during the nights of late summer and fall is an instance of this fact. Tyndall, the English scientist, has expressed this point very strongly in the following manner: "Aqueous vapor is a blanket more necessary to the vegetable life of England than clothing is to man. Remove for a single night the aqueous vapor from the air which overspreads this country, and every plant capable of being destroyed by a freeezing temperature would perish. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost."

Relation of Water to the Soil. Water is one of the most important factors concerned in the formation of soils and the changes that take place in soils. Without water soils would never have been formed. A certain amount of water is necessary for the changes that are vital to agriculture. Yet, as already pointed out, too much water may cause erosion and rapid loss of fertility. The water supply is the factor in plant production which is often the least controllable, and, therefore, the most vital. For this reason everything which aids in any way the absorption and retention of water in soils or which prevents undue loss of water is to be promoted to the utmost. The control of soil moisture is the subject of special study in soil physics and in so-called *dry farming.*

One important manner in which water affects soil formation is by the expansion of ice in rock crevices and in soil lumps. By this means large rocks are gradually broken down into soil particles and clods of earth into finer portions. The great usefulness of this action is seen in fall plowing, after which nature with little effort efficiently pulverizes and cultivates the soil.

Relation of Water to Plant Life. The importance of this relation can hardly be realized. Water serves plants in a number of vital ways. It helps transport food from the soil and from one part of the plant to another. It regulates the temperature of the plant. It maintains the turgidity of the cells and gives form and rigidity to the plant while in active growth. It is the most abundant constituent of plant tissues. It is an important constituent of the organic compounds produced by the plant in its growth. Water, moreover, combines with some soil compounds, making them soluble, so that they can be more readily taken up by plants.

In countries of limited rainfall, *irrigation* is necessary before crops can be raised. It is very important that the character of the water be such that it will not injure the plants. If the water contains common salt, sodium carbonate, or other soluble compounds, these substances may accumulate in the soil and rise to the surface upon evaporation, giving the effect commonly called *alkali*. In other cases, lowlands or lands adjacent to rivers are sometimes overflowed with muddy water. In this manner a sediment of finely divided particles is formed. This is rich in plant food and enormously increases the fertility of lands subjected to that treatment. In certain localities lands are systematically treated in this way. The valley of the Nile is a notable example.

Relation of Water to Animal Life. Water is as vital to the life of the animal as it is to plants. In a general way, it may be said to perform somewhat the same functions. The principal constituent of animal bodies is water. It is necessary for the digestion process and the transfer of the important body fluids. It helps to equalize the temperature of the animal body with external conditions.

The question of drinking water is one in which we are all interested. The substances present in the water may or may not affect its usefulness in this respect. Those materials dissolved out of rocks and minerals are usually not harmful to the animal system. A certain amount of such matter is advantageous since it helps supply the mineral constituents of the solid tissues of the body. But a large amount of dissolved minerals may be quite harmful, the extent depending upon the nature of the substances. The presence of organic matter is also to be avoided, because it indicates possible contamination by sewage. The latter may consist of the products of animal life and the bacteria which usually accompany such products. Some of these bacteria may be those which are characteristic of certain contagious diseases. In this way typhoid fever and other dread diseases may be spread. It is, therefore, important to ascertain the presence of such organic compounds and to purify the water by suitable means, so that it can be safely used for drinking purposes.

In the Arts. Water is necessary in a large number of manufacturing processes for *cleansing purposes*. For example, its importance in connection with the textile industries is very great. The *bleaching and dyeing* as well as cleansing processes require large quantities of water for their successful operation. Water is the most common solvent used in chemical works.

One factor which limits the use of water in the household and in industry is the so-called *hardness* of water. The effects of hard waters are so well known that they hardly need naming. Every student can tell the difference between hard and soft waters by their effect upon soap. The curd or scum which hard water forms with soap is not at all pleasant or desirable in laundering or industrial processes. It not only interferes with the actual cleansing operation but also adds to the cost. The scale or sediment in the bottom of a tea kettle or in the tubes of a boiler is another result of the use of hard waters. Such a residue adds inconvenience and increases the cost of the operation. The cause of the hardness of water and the methods of overcoming this characteristic will be treated more fully in the discussion of calcium.

OXYGEN

Introduction. Oxygen is often called the most important element. It is the most abundant element and is very active chemically. It is absolutely necessary for the processes of plant and animal respiration and of combustion. Among the other changes caused by oxygen are the decay of wood and other organic matter, the fermenting of fruit juices, and the rusting or tarnishing of metals.

Distribution. Oxygen forms 47% or nearly one half the weight of the earth's crust. It is eight ninths by weight of pure water, but only 86% of the ocean. What is the cause of this difference? The atmosphere contains 23% or about one quarter by weight of oxygen. This element is also an important constituent of plant and animal life. In every one of these cases, except the atmosphere, the oxygen is in the combined form. In the atmosphere it is in the free or uncombined form.

Preparation. Oxygen can be quite readily prepared in a number of different ways. Its liberation from water by passing an electric current through the latter has been shown already. Oxygen may also be prepared by liquefying the air and allowing the liquid nitrogen of the air to boil away. The liquid oxygen remains almost pure.

The most common method, though, of preparing the element is to heat an oxide* or a peroxide of some metal, compound which will readily surrender its oxygen, potassium chlorate, for example. By heating it to 350-400°C. oxygen is liberated as a gas and can be collected over water. When all the oxygen is expelled by applying sufficient heat, a white solid, potassium chloride, remains as a non-volatile residue in the apparatus. Red oxide of

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* See note in appendix.

mercury, barium peroxide, and red lead, an oxide of lead, are other compounds which give off oxygen upon being heated. Usually, however, a mixture of potassium chlorate and manganese dioxide is employed. The oxygen is produced from this mixture easily and at a low temperature, about 200°C. The apparatus which is used for the preparation of oxygen by this method may be simple, as demonstrated in

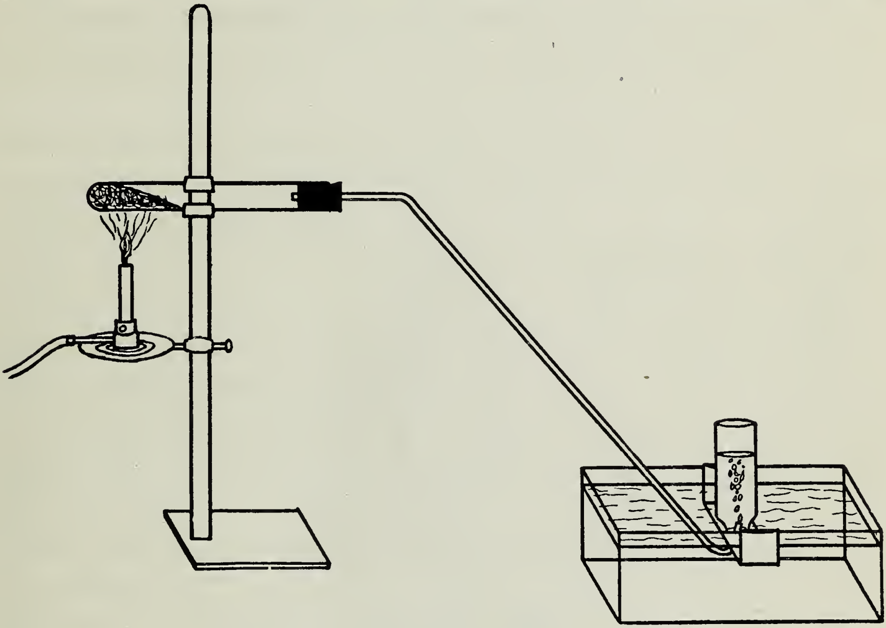


Figure 12.—The preparation of oxygen.

Figure 12. The mixture of four parts of potassium chlorate and one part of manganese dioxide is placed in the hand glass tube at the left; the latter is heated at first carefully, then finally to a high temperature to drive off the oxygen through the long glass tube. The gas is collected in the bottle by displacement of water. A number of bottles may be filled with water and inverted in the pneumatic trough to be filled with the oxygen. It is always best to first heat a small portion of the mixture of potassium chlorate and manganese dioxide in an open test tube to be sure that there will be no explosion in the larger flask.

It has been found that, if the potassium chlorate is heated to drive off all the oxygen possible, the latter is always 39.18% of the weight of the original substance. In other words, there is a definite proportion of oxygen combined with the potassium and chlorine to form potassium chlorate. This same phenomenon is true of every chemical compound and the law which is used to express it is called the *law of definite proportions.* A chemical compound always contains the same elements in the same proportion by weight.

There is still another type of reaction for generating oxygen from peroxides, that is by the action of water upon them. Figure 13 illustrates the different parts of an autogenor which uses sodium peroxide for this purpose. The cakes of fused peroxide are placed in the inner cylinder (1) and kept in place by the spring holder (10). The inside of the apparatus (A) is then fitted into the outside tank (B) which has been previously nearly filled with water. The complete apparatus is shown in (C). The oxygen which is evolved may be passed through a nebulizer or spray and is used in the medical profession and in cases of first aid to suffocating persons. The whole outfit is a convenient and portable apparatus for the purpose intended.

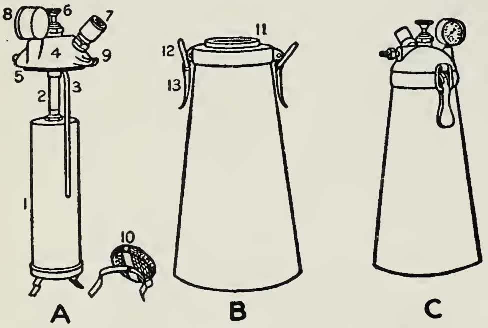


Figure 13.—An automatic arrangement for generating oxygen.

Physical Properties. Under ordinary conditions of pressure and temperature, oxygen is a colorless, odorless, and tasteless gas. It is slightly heavier than the atmosphere, one liter weighing 1.43 grams under standard conditions. The volume of gases varies with temperature and pressure; the greater the temperature, with constant pressure, the greater the volume of the gas; the greater the pressure, with constant temperature, the smaller the volume of the gas. Evidently, therefore, there must be some standard conditions for comparing gas volumes. Those commonly used are 0°C. and 760 m.m., the average pressure exerted by the atmosphere at sea level. For a further study of gas volumes the student is referred to textbooks of physics.

Oxygen may be liquefied by lowering the temperature and increasing the pressure. It is then pale blue in color and boils at −182.5°C. By further cooling, snow white crystals of the substance may be obtained, which melt at −227°C. Oxygen is only slightly soluble in water, about five volumes being held in solution in 100 volumes of water at 0°C. At 20°C. only about three volumes are soluble, yet this is sufficient to add desirable qualities to drinking water and furnish the oxygen by which fish and other organisms living in water are able to sustain their life.

Chemical Properties. Oxygen is a very active element, combining with all the other elements except fluorine and the members of the argon group. Several elements, however, will not combine directly with oxygen, but can be made to do so by various indirect steps. This characteristic of the general activity of oxygen distinguishes it from the other elements. In some cases oxygen may form more than one compound with another element. Such compounds are usually called oxides. They may be formed by direct union of the element with oxygen, either in the air under ordinary conditions or in pure oxygen with or without the application of heat.

After a few bottles of oxygen have been collected, the gas can be tested. A square piece of glass is placed over the mouth of the bottle which can then be removed from the trough. The bottle is inverted as shown in Figure 14a, the glass is moved to one side and a piece of smouldering charcoal is lowered into the oxygen. Immediately the charcoal glows intensely. (14b). Even fine iron wire, if heated to the required temperature by burning sulphur, burns and throws off red hot sparks of iron oxide. (14c). In this way it can be shown that substances which burn in the air burn much more intensely in pure oxygen; also that materials that oxidize slowly in the air do so much more rapidly in pure oxygen. It can also be proved that it is the oxygen of the air which supports combustion, and that the other constituents of the air retard it.

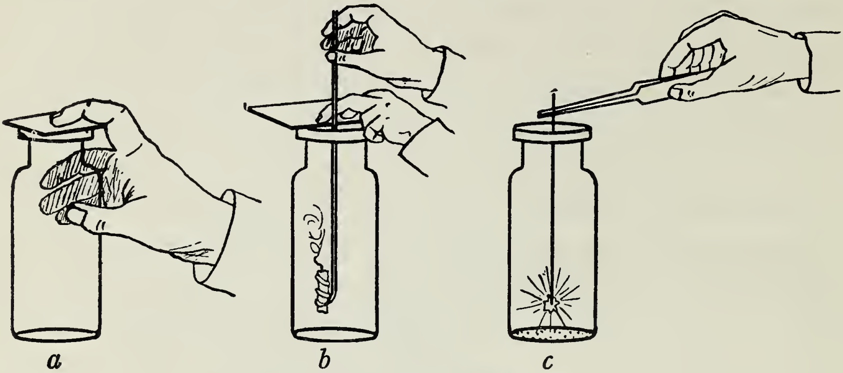


Figure 14.—Testing oxygen gas.

Oxidation. Such processes as the above are called *oxidation,* a more common name being combustion. They are usually attended by an evolution of light and heat. Oxidation may be quick or slow, depending upon the material oxidized and the conditions of the process. The rusting of metals in a moist atmosphere is an example of slow oxidation. Other examples are the decay of organic and vegetable matter and the drying of linseed oil in paint mixtures.

Heat must be supplied in order to start certain oxidations. It may be either the ordinary heat of the atmosphere or heat furnished artificially. When one portion of a suitable substance has been oxidized, the heat given off may be sufficient to carry on the oxidation of the other portions. In some cases, however, the heat evolved is not sufficient to maintain the process and heat must be continually added from external sources in order to keep the process active. Oxidation may sometimes proceed under ordinary atmospheric conditions. Heat is liberated in small quantities, but enough to gradually raise the temperature of the matter concerned. The oxidation is quickened by this process until it reaches the point where *flame and fire* result. This is frequently called *spontaneous combustion.* Instances of this action are seen where coal dust, sawdust, thin films of oil upon cotton waste, or wood saturated with oil have been exposed to the air for some time. The material slowly oxidizes, the heat afforded by the oxidation raises the temperature of the mass, and, ultimately, if the process is allowed to proceed, a fire may result.

Frequently the process of combustion is forced, as, for example, in the boilers of engines and in blast furnaces. Air or oxygen is forced under pressure into the furnace. This not only furnishes fresh portions of oxygen to hasten the burning of the fuel, but also sweeps away the products of combustion which retard it. The same principle is seen also in heating stoves and furnaces. By increasing the draught, combustion is quickened and more heat is liberated.

The term *deflagration* is applied to an oxidation of a special type. The combination of the combustible substances and the oxidizing agent takes place almost instantaneously through the whole mixture. Gunpowder is an example of a substance that deflagrates when ignited in the open air.

Kindling Temperature. The temperature at which a combustible substance begins to burn is called its *kindling, or ignition, temperature.* This point varies considerably with the nature of the substance. Some materials, such as gasoline, will ignite at a point only slightly above the temperature of the air. Others such as hard coal, require a very high temperature before they are oxidized. In practice it is necessary to use some substance which ignites at a relatively low temperature in order to cause other substances to burn. Common examples of this application are seen in the case of the match and the building of a fire in a stove or furnace. In the first case the head of the match which has been prepared from a mixture of chemicals, is ignited by heat generated by simple friction. The heat produced from the intense chemical reaction raises the temperature of the wood to the point at which it in turn ignites. In the stove fire, we use first a layer of paper, then of wood, then of coal. By lighting the paper, which burns at a very low temperature, heat is generated to ignite the wood, and this in turn produces heat to cause the coal to ignite; whereas it would have been simply impossible to ignite the coal with the match used in the first instance.

It is possible to extinguish a fire by lowering the temperature below the kindling point. If we blow out a match we have simply lowered the temperature of the wood below the point at which it burns. An interesting application of this principle is the *safety lamp* which is used by miners to prevent explosions of gases in mines. The lamp is an ordinary lantern surrounded by wire gauze. When it is brought into an explosive gaseous mixture, the gases diffuse through the wire gauze, and burn inside the lamp, but the heat produced is carried away by the gauze, so that the gases outside the lamp do not reach the ignition temperature. The small explosions inside the lamp warn the miner of his danger and he can escape from the mine before any accident happens.

Uses of Oxygen. Oxygen performs two functions of great importance to mankind. First, it is a *supporter of combustion.* Combustion may be either the active process by which heat and light are evolved, or certain slow processes of animal and vegetable matter by which little heat is liberated, such as decay and fermentation. The rusting of metals might also be included under this head.

Second, oxygen is a *supporter of animal respiration.* This is really a slow combustion in all parts of the body to which the oxygen is carried. In this manner, heat is produced and energy afforded to the animal to carry out the different functions of the body. Oxygen is especially fitted for this function for several reasons. It is so abundant in the atmosphere. It is soluble in water, thus aiding fish life. It does not irritate the lungs. The products of animal respiration, water and carbon dioxide, are not corrosive to animal tissue. The volume of oxygen consumed and that of the carbon dioxide produced are the same and, therefore, no pressure is exerted either way. The effect upon animals of removing the oxygen of the air is to cause suffocation and death, while increase in the percentage of oxygen leads to increased activities within certain limits. The effect of pure oxygen upon animals would be that of a poison, producing intense inflammation, convulsions, and death. On the other hand, one can breathe pure oxygen for a time without bad effect, in fact the gas is frequently administered to persons who are ill and who experience difficulty in breathing. Helmets equipped with oxygen attachments enable the diver to descend to ocean depths, the aviator to ascend into rarified air, the fireman to stand in dense smoke, and rescuers to descend into gas-filled mines.

Figure 15.—Iron cylinders, for storing and shipping gases.

Oxygen is moreover an article of commerce and is largely used in various industries. It may be generated locally and used directly for the purpose intended, or it may be stored under pressure in wrought iron cylinders (such as shown in Figure 15) and thus shipped wherever it may be required. Mention should be made of the application of the oxy-acetylene and oxy-hydrogen processes in the industries.

OZONE

Preparation. Ozone may be prepared from oxygen or air by passing electric sparks through these gases. In this manner a small amount of the oxygen is converted to ozone. There are certain chemical methods also of preparing the substance, for example, if some pieces of phosphorus are placed in a bottle and partially covered with water, the presence of ozone may soon be detected.

Properties. Ozone is a colorless gas having the characteristic odor which is noticeable about electrical machines when they are in operation. It may be liquefied and is then blue in color and boils at −119°C.

Chemically, ozone is similar to oxygen but is much more active. It is very explosive and is converted into oxygen with the liberation of heat. On account of its activity and oxidizing properties ozone is used in certain manufacturing processes and for purifying water and air.

Relation of Oxygen and Ozone. When oxygen is converted into ozone there is a *change of volume*, three volumes of oxygen forming two volumes of ozone. If this ozone is then heated to about 300°C. the reverse change occurs, two volumes of ozone being changed to three volumes of oxygen. In this phenomenon no other kind of matter is involved. But there is to be considered the question of energy. It may be proved in a number of ways that oxygen and ozone contain different amounts of energy; for example, by the fact that heat is liberated when ozone reverts to oxygen. The passage of the electric sparks through the oxygen has in some way changed the amount of energy of this substance and it has acquired new properties. Oxygen and ozone are, therefore, the same kind of matter, but have different energy contents. When an element exists in different forms, such as the example just cited, these are called *allotropic* states or forms of the element. There are a number of other elements which possess this property of allotropism.

HYDROGEN

Introduction. Hydrogen is a gas and *the lightest substance known.* It is found in a large number of substances, but is not of very great importance as an element. Hydrogen is most useful in its combined forms, such as water and the organic compounds of plant and animal life. With few exceptions it is not a very active element.

Distribution. In the free form hydrogen has been proved to exist in enormous quantities in the atmosphere of the sun. It does not occur in very great quantity in the earth, though it is sometimes found in the atmosphere near large cities and volcanoes. In the combined form hydrogen exists in a great many natural and artificial substances. One ninth of the weight of water is hydrogen. Vegetable and animal matter contain this element. Fuels, such as petroleum, coal, illuminating and heating gases, and wood all contain hydrogen. It is also a constituent of all acids and bases and is found, moreover, in a large number of chemical compounds, as ammonia and hydrogen sulphide.

Preparation. Hydrogen may be prepared in a number of different ways for experimental purposes. Since it does not occur free in nature, it must be secured from some of its compounds. The simplest compounds containing this element and those which most easily liberate it are water and the common acids. Some means, therefore, of decomposing water or the acids is utilized for preparing the element.

The most convenient method is the reaction between metals and dilute acids, simple contact under ordinary conditions being the essential qualifications. Zinc and iron are the metals usually employed, and hydrochloric acid and sulphuric acid the acids.

In Figure 16 is shown a simple apparatus for generating hydrogen. The acid is poured through the thistle tube B into the flask A which contains the metal. The hydrogen is at once liberated as a gas and passes off through the tube C. It may be collected in bottles over water as in the preparation of oxygen. As considerable heat is evolved by the process, there is no need of heating the flask, in fact *no flame should be near a hydrogen generator.*

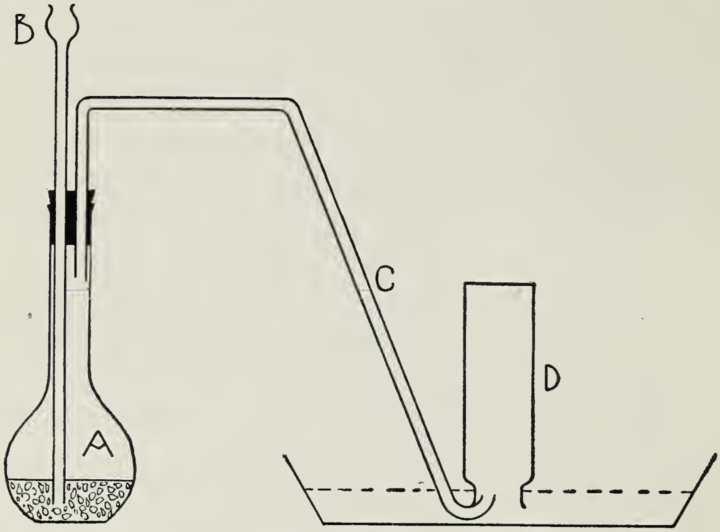


Figure 16.—The preparation of hydrogen.

Water serves as a convenient material for preparing hydrogen, since it is the most common compound of the element. It will be recalled that hydrogen is one of the two substances given off by the electrolysis of water. Metals also were shown to have an effect upon water and to liberate hydrogen. Though there is a number of metals which do this, sodium and potassium are the ones which are most commonly used for experimental purposes. Figure 17 shows the reaction of a piece of sodium upon water. A lead-sodium alloy is also used for this reaction. If steam is passed over red hot iron, hydrogen is liberated and may be collected; iron oxide is the other product.

Physical Properties. Hydrogen is a colorless, odorless, and tasteless gas. It is the lightest substance known. One liter of hydrogen at 0°C. and 760 m.m. weighs only 0.0896 gram. Comparing equal volumes, air is 14.4 times, oxygen is 16 times, and water is 11,000 times heavier than hydrogen.

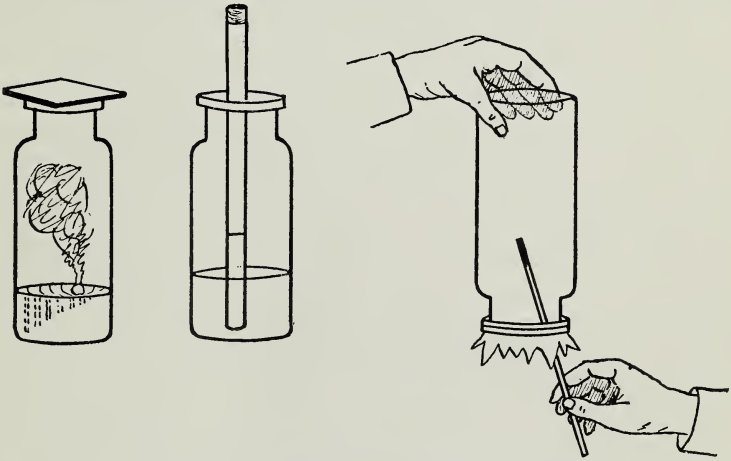


Figure 17.—Experiments with hydrogen.

It is not very soluble in water, being about half as soluble as oxygen. Hydrogen is, however, absorbed by several metals, especially palladium, a process which is called *occlusion.* Enough heat is developed by this action to ignite the gas. Hydrogen also illustrates the phenomenon of *diffusion.* It readily passes through porous substances and mixes with other gases. Figure 17 shows a tube which has a plaster of Paris cap at one end. After the tube is filled with hydrogen and inserted in water, the gas passes out through the plaster cap faster than the air can enter. Water rushes in and takes the place of the hydrogen lost in this way. Since the rate of diffusion of a gas is inversely proportional to the square root of its density, hydrogen diffuses more rapidly than any other substance. By lowering the temperature and increasing the pressure hydrogen may be liquefied and even solidified. It conducts heat and electricity better than any other gas.

Chemical Properties. Hydrogen burns, but does not support combustion. With oxygen, either pure or from the air, it forms water. This reaction may be induced by thrusting a lighted taper into a mixture of oxygen and hydrogen or by passing an electric spark through the mixture. The two gases unite so violently that an *explosion* may result, hence care should be used in testing hydrogen. With chlorine hydrogen forms hydrochloric acid, a reaction which may be effected in a manner similar to the union of oxygen and hydrogen. With a number of other elements hydrogen unites to give corresponding hydrogen compounds. With these exceptions hydrogen is a comparatively inert material at ordinary temperatures. Figure 17 illustrates a characteristic experiment with hydrogen. A bottle containing the element is inverted and a burning stick thrust up into the gas. The lighted stick is at once extinguished, but the hydrogen catches fire and burns at the mouth of the bottle with an almost invisible but very hot flame.

The reaction of hydrogen and oxygen is very characteristic of these two elements. Hydrogen will react with free oxygen or combined oxygen. In other words, it will abstract oxygen from its combination with other elements. This process is, therefore, the reverse of adding oxygen to an element. The term *reduction* is applied to the removal of oxygen from a substance. What is the term applied to the addition of oxygen? Reduction processes are of great industrial importance, since many metals are abstracted from their ores in this manner. As will be discussed later, other substances, as carbon and aluminium, are used, as well as hydrogen, to effect reduction.

Usefulness. In the free form hydrogen has a few uses, as a reagent for laboratory purposes, a reducing agent in metallurgical processes and a material for filling balloons, especially those that are to travel some distance. Hydrogen is also a constituent of water gas, producer gas, and artificial and natural illuminating gases which are valuable for their commercial purposes. Advantage is taken of the large amount of heat produced by the combination of hydrogen with oxygen in the *oxy-hydrogen blowpipe.* By directing the flame from this burner against a piece of lime or other substance which is difficult to melt, the lime becomes intensely bright. It is called the *lime, calcium, or Drummond light,* and is employed in operating the stereopticon.

In the combined form hydrogen is of great importance in its different compounds, such as water, acids, and the compounds of plant and animal life. The applications of hydrogen in these connections may be inferred from the discussion of those substances.

HYDROGEN PEROXIDE

Introduction. Besides water there is another compound of hydrogen and oxygen which contains twice as much oxygen in proportion to the hydrogen as water. This substance is commonly called hydrogen dioxide or hydrogen peroxide.

Preparation. Hydrogen peroxide is usually prepared by the action of dilute sulphuric acid on barium peroxide. The dilute solution of the hydrogen peroxide thus formed may be concentrated by carefully distilling off the water.

Properties. Hydrogen peroxide, when pure, is a colorless syrupy liquid with a specific gravity of 1.49. It is easily decomposed into water and oxygen, this being its most characteristic property. If prepared in the form of a dilute solution, it is then quite stable, though it should be kept in a dark cool place, since both light and heat aid in its decomposition.

Uses. In the form of a 3% solution, peroxide of hydrogen is a common preparation to be secured from druggists.

It is used in medicine and in the household as an antiseptic. This usefulness, as well as the other commercial purposes for which it is employed, depends upon the strong oxidizing properties of the compound.

THE RELATION OF WATER, HYDROGEN, AND OXYGEN

The student has now become familiar with the fact that water is a compound which can be decomposed into two elements, hydrogen and oxygen. He has also studied the properties of all three of these substances. There has undoubtedly come to his mind these questions, in regard to them. What is the weight of the gases hydrogen and oxygen, which can be secured from a given amount of water? How can this *gravimetric relation* be proved?

The composition of a compound is determined by *analysis* and *synthesis*, which mean *taking apart* and *putting together*. As far as possible, it is better to use both these methods, as they strengthen each other in reaching a final conclusion. Both analysis and synthesis can be *qualitative* or *quantitative*. These names practically suggest their meaning; qualitative, the *quality or kind*, and quantitative, the *amount* of substances involved. In other words, a qualitative study asks, *What does the substance contain?* and a quantitative study, *How much does the substance contain?*

The composition of water is an excellent subject for applying the methods of analysis and synthesis. A special form of analysis, electrolysis, and two other methods, the action of metals and of chlorine, have been studied in a qualitative manner. Let us now turn to the question of the *quantitative composition* of water. It has already been stated that from the electrolysis of water only hydrogen and oxygen are produced and that their ratio by volume is two to one. The complete proof, however, that these two gases are united in the same proportion in water follows from the *volumetric synthesis* of water. Figure 18 shows the apparatus which is used to demonstrate this experiment. A tube closed at one end, a *eudiometer,* is filled with mercury. Two volumes of hydrogen and one volume of oxygen are passed into the tube and displace part of the mercury; by raising or lowering the leveling tube on the right it is possible to get the volume of the gases at atmospheric pressure. The tube containing the gases is now surrounded by a steam jacket and steam is passed through until the volume of the gases becomes constant. An electric spark is sent through the mixture in the inner tube and the union of the hydrogen and oxygen thus effected. The steam is again passed through the jacket and the volume of the gases read a second time. The volume is now only two thirds as great as that of the original gases. The substance is in the form of steam, since the purpose of the outer steam jacket is to compare the volumes of all the gases at the same temperature. In this way it can be proved that *two volumes of hydrogen and one volume of oxygen unite to form two volumes of water vapor.* The experiment proves that the proportion by volume in which hydrogen and oxygen combine in the production of water is the same as that in which these gases are obtained from water. It can also be shown that the sum of the weights of hydrogen and oxygen equals the weight of the water produced.

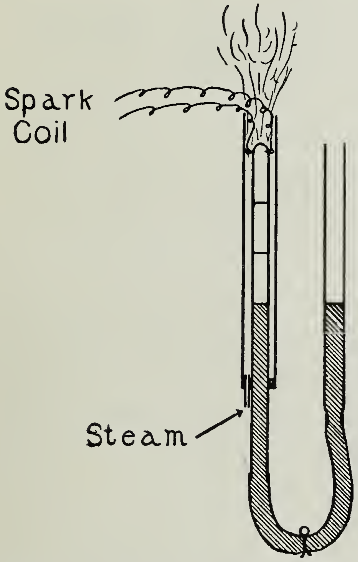


Figure 18.—The volumetric synthesis of water.

It is now necessary to know the *proportion by weight* in which hydrogen and oxygen are combined in water. Figure 19 shows the apparatus which can be used to ascertain this. A known weight of copper oxide is placed in the tube D.

While this is heated, a current of pure hydrogen is passed over it. The hydrogen unites with the oxygen of the copper oxide and forms water, leaving the copper behind in the tube. The water is absorbed in the tube E and its weight determined. The weight of the remaining copper can also be secured. Since the loss of the weight of the copper oxide is oxygen and the gain in the weight of the U-tube E is water, the difference between these two weights is hydrogen. Hence it is a simple matter to establish the quantitative relation of these three substances. The result of many such experiments has proved the relation to be as follows:

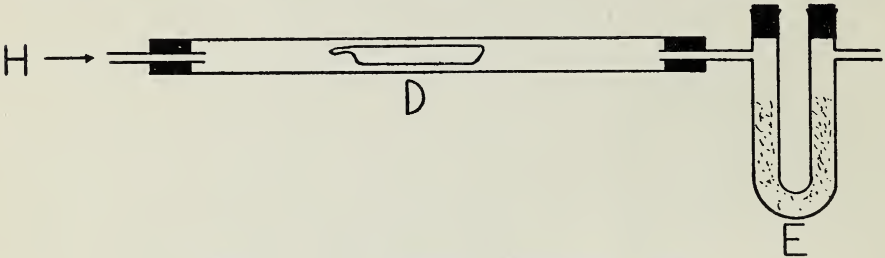


Figure 19.—The gravimetric synthesis of water.

Oxygen	Hydrogen	Water
8 parts	1 part	9 parts

For reasons which will be given later, it is more convenient to state the composition of water by weight as 16 parts of oxygen to 2 parts of hydrogen.

If the student now compares the weights of equal volumes of hydrogen and oxygen (see physical properties), he will find that *oxygen is sixteen times heavier than hydrogen.* The one volume of oxygen produced from the electrolysis of water, therefore, must be *eight times heavier than the two volumes of hydrogen.* But this is the ratio actually found in determining the gravimetric composition of water. Hence, the composition of water is said to be (1) *by weight, one part hydrogen and eight parts oxygen,* and (2) *by volume, two parts hydrogen and one part oxygen.*

ATOMS, MOLECULES, ATOMIC WEIGHTS

Molecules. According to the *atomic* theory all substances are made up of minute particles, called molecules. These are the smallest particle of an element or a compound which is capable of existing alone and retaining most of the properties of the mass of the original substance. The molecules of a pure substance are exactly alike, but different from those of every other substance. One difference is their mass, or weight.

Atoms. The molecules of a substance are composed of particles of the elements which constitute it. If the substance is an element, the particles are all alike; if the substance is a compound, there may be several different kinds of particles. Such particles are called *atoms*. *Molecules, then, are groups of atoms held together by chemical attraction.*

An atom is the smallest particle of a substance. It does not exist alone but is always combined with other atoms to form molecules. There are as many kinds of atoms as of elements. They are extremely small, indivisible and unchangeable by any physical or chemical means. They exhibit an attractive force for other atoms which varies under different conditions and with the different elements.

Atomic Weights. If the molecules have weight, then the atoms composing them also have weight. It has been possible by experimenting and reasoning to assign to the different atoms *relative weights*. Since hydrogen is the lightest substance known, it may be concluded that it has the lightest atom. For the sake of convenience, therefore, the atomic weight of hydrogen can be taken as unity, or 1.0, and used as a standard for other atomic weights. Oxygen is nearly 16 times as heavy as hydrogen, the actual ratio is 15.87. For several reasons it is now preferred to use the atomic weight of oxygen as the standard with a value of 16, in which case the atomic weight of hydrogen becomes 1.008. One cause for this preference is the fact that oxygen combines with practically all the other elements. What advantage has that feature over the use of hydrogen as the standard? A complete list of atomic weights appears in the appendix in the table of elements. The student should appreciate the fact that *these atomic weights are only relative,* that is, comparative to some standard, since the atomic masses are too small to be weighed absolutely.

SYMBOLS, FORMULAS, EQUATIONS

Symbols. It is desirable as far as possible to simplify the manner of expressing chemical reactions. We may assign to each element a certain letter or group of letters, called a *symbol.* The letter chosen is usually the initial one in the name of the element or a second letter in addition to the first, when there are two or more elements beginning with the same initial. For example, C stands for carbon, Cl for chlorine, Co for cobalt, and Cu for copper. The Latin name for copper is *cuprum,* hence the symbol Cu. The student will gradually become familiar with these and other symbols and appreciate their convenience as shorthand expressions for chemical names.

Formulas. A compound is composed of two or more elements; hence there will be in the abbreviated expression, called *formula,* for these compounds two or more symbols depending upon the kind of elements present and their amount. Formulas are more difficult to learn and will be studied in connection with their respective compounds.

Equations. If we wish to express a chemical reaction, we may do so by grouping the symbols or formulas of the substances taking part in the reaction into an *equation.* The materials at the beginning of the reaction are placed on the left-hand side of the equation and are known as *factors.* Those substances formed by the reaction are placed on the right-hand side and are called *products.* Instead of the usual sign of equality, however, an arrow is placed between the halves as →. Sometimes a reaction may be *reversed* and proceed in two ways at the same time, when the double arrow ⇄ is used. An equation, therefore, is merely a convenient method of expressing a chemical reaction by using the formulas of the reacting materials. It should be kept in mind that equations are the results of experiments. When it is known what substances take part in a reaction, then it is possible to write the equation for that reaction. Not only are the actual kinds of matter involved indicated in equations, but the latter have a quantitative meaning as well. The *proportions by weight* of the reacting substances and of the products, and further, when gases are concerned, the *proportions by volume*, may all be shown in equations. The student should not place the learning of the equation above the fact represented by the equation. As he becomes familiar with chemical reactions, he will become accustomed to the use of equations. The fact is the important thing to learn; the equation is second.

It might be well to apply the points just under discussion to a few reactions which have been already studied. Take for example the electrolysis of water.

$$\begin{array}{ccc} \left.\begin{array}{l}\text{Hydrogen}\\ \text{Oxygen}\end{array}\right\} & \rightarrow & \text{Hydrogen and Oxygen} \\ \text{Water} & \begin{array}{c}\text{By}\\ \text{Electrolysis}\end{array} & \\ 2\,H_2O & \rightarrow & 2\,H_2+O_2 \end{array}$$

The formula for water is H_2O. Two molecules are taken in the equation to represent the fact that two molecules of hydrogen are formed and one molecule of oxygen. It will be recalled that this is in accordance with the fact that two volumes of hydrogen and one volume of oxygen are liberated by the electrolysis of water; also that the molecule of these two elements is composed of two atoms. If the equation factors were divided by two, only one atom of oxygen would appear. This would not be in harmony with the view that the molecule is the smallest part of a substance that can exist alone and retain the properties of the original material. For this reason and others it is preferable to write equations in the *molecular* form instead of the *atomic* form. The proportions by weight are also shown to be that 18 parts of water give 2 parts of hydrogen and 16 parts of oxygen.

Another example of an equation is the action of sodium upon water:

$$\underset{\text{Water}}{\left.\begin{matrix}\text{Hydrogen}\\ \text{Oxygen}\end{matrix}\right\}}\text{and Sodium} \quad \rightarrow \quad \text{Hydrogen and}\underset{\text{Sodium hydroxide}}{\left\{\begin{matrix}\text{Sodium}\\ \text{Hydrogen}\\ \text{Oxygen}\end{matrix}\right.}$$

$$2\,H_2O \quad + \quad Na_2 \quad \rightarrow \quad H_2 \quad + \quad 2\,NaOH$$

This equation represents the fact that two molecules of water react with a molecule of sodium to form a molecule of hydrogen and two of sodium hydroxide. It is evident that only half of the hydrogen of water is replaced by sodium in this action. The other portion of hydrogen is combined with sodium and oxygen to form sodium hydroxide, or caustic soda.

In the preparation of oxygen by heating potassium chlorate two molecules of potassium chlorate are changed into three molecules of oxygen and two of potassium chloride. The equation is

$$2\,KClO_3\ (\text{heated}) \quad \rightarrow \quad 3\,O_2 \quad + \quad 2\,KCl.$$

In other words by heating two *molecular weights* of potassium chlorate, three molecular weights of oxygen are produced. Further examples of equations will appear in connection with their reactions.

SUMMARY

Water is probably the most familiar example of a chemical compound. Its importance is shown by the facts that it is partly responsible for the present appearance of the earth's surface, that it is absolutely necessary for plant and animal life, that it affects climatic conditions and that it is a necessity in commerce and industry. Water is very widely distributed not only as bodies of free water but also in close association with the vegetable, animal, and mineral kingdoms. There are many different kinds of natural waters, all of which are more or less closely related in a constant circulation. These natural forms are not pure, since there are many foreign materials dissolved by water in its cycle. Water may, however, be purified by distillation.

The physical properties of water make it of the utmost value to man. It is the most familiar illustration of a substance that can exist in three states of matter without change of composition. As a liquid, its solvent properties are important; as a gas, steam, it is of untold value for industrial purposes; as a solid, ice, it causes many changes of importance in nature.

Water is a compound of oxygen and hydrogen. This may be proved by decomposing it by electrolysis, by the action of metals, and by the action of chlorine. As a chemical agent, water combines directly with other substances, it aids the interaction of two or more substances, and is responsible for such common processes as rusting and decay.

Oxygen is one of the most important elements, if not the most important element known. The following facts may be taken as proof of this statement. It is the most abundant element, and, while not the most active, combines with nearly all the other elements. Oxygen is directly responsible for the changes brought about by the breathing of animals, the burning of fuels, the rusting of metals, and the decay of vegetable and animal tissues. Under ordinary conditions oxygen is a gas. It has an allotropic form, known as ozone, which is more active than oxygen. Oxygen may be prepared in a number of ways by the decomposition of water and oxides, and from the atmosphere. So wide are its uses that about 4,000,000 cubic feet of the gas are bottled in the United States every year.

Hydrogen is the lightest known substance. While ordinarily a gas, it may be liquefied. It is widely distributed in nature in the form of compounds, the principal one of which is water. Hydrogen is usually prepared from water or acids by the action of metals. With the exception of its attraction for oxygen, chlorine and a few other elements, it is not very active. The greatest usefulness of hydrogen is in its combinations with these few elements, such as oxygen, carbon, chlorine, and nitrogen.

An atom is the smallest part of a substance that can react with other substances. A molecule is the smallest particle of a substance that can exist alone. Molecules are composed of atoms. Atoms and molecules have mass or weight. Since it is impossible to determine the absolute weight of these very small particles of matter, their relative weights are used. In the case of atoms, these are called atomic weights; in the case of molecules, they are called molecular weights. Molecular weights are the sum of the atomic weights of the substances composing the molecule. Hydrogen and oxygen are taken as standards for atomic weights.

A symbol is an abbreviation for the name of an element. A formula is used to represent a compound and is a group of symbols of the elements composing the compound. An equation is an expression, by means of formulas, of a chemical reaction. In this way the kinds of matter, their proportions by weight, and if gases, their proportions by volume may be conveniently represented.

QUESTIONS

1. What conditions affect the composition of natural waters?
2. What impurities may be present in different natural waters?
3. Why does water from some natural springs effervesce?
4. What are important characteristics of good drinking water?
5. Given three kinds of water, distilled, artesian and rain, how could you determine each kind?
6. In what ways can water be decomposed?
7. Compare the solubility of solids and gases in water, especially considering the effect of temperature and pressure upon the amount of material dissolved.
8. What are some of the principal differences between oxygen and hydrogen?
9. Compare the properties of ozone with those of oxygen.
10. State some tests by which you can tell the differences between water and hydrogen peroxide; between oxygen and ozone.
11. Would pure hydrogen make a good illuminating gas? Would a Welsbach burner supplied with hydrogen give light?
12. Is it safe to hunt for a gas leak with a lighted match?
13. What is meant by the expressions: combustion, oxidation, slow oxidation, spontaneous combustion?
14. What phenomena usually accompany combustion?
15. In what respect does the rusting of iron differ from the burning of iron in oxygen?
16. Does anything collect on the inside of a lamp chimney when first lighted? Does it remain very long?
17. Why are metal cans provided for the oily waste in wood turning shops?
18. Describe one method by which the quantitative relation of hydrogen, oxygen and water may be proved.
19. State what is meant by the expressions: atom, molecule, formula, equation, catalytic agent, allotropic form.

CHAPTER III

THE ATMOSPHERE AND ITS CHIEF CONSTITUENT, NITROGEN

THE ATMOSPHERE

Introduction. The gaseous mantle, or envelope, surrounding our earth is called its *atmosphere*. It is also commonly called the *air*. It is somewhat like a gaseous ocean with a depth of from forty to fifty miles, though it is believed that portions of its gases exist as far as two hundred miles from the earth's surface. The atmosphere is a mixture of a number of gases, the most important of which are nitrogen, oxygen, carbon dioxide, and water vapor. Some of its ingredients are fairly constant in amount, while others are variable. These gases possess, in the aggregate, enormous weight, due to the attractive force exerted between the earth and the atmosphere. This amounts to 15 pounds per square inch at sea level, or 41,300 tons for each acre of the earth's surface. The atmosphere furnishes a supply of oxygen for respiration. Over 90% of the food of plants comes from the atmosphere and it is a valuable factor in the continual round of certain kinds of matter, as water, nitrogen, etc.

Composition of the Air. The principal components of the air are nitrogen and oxygen. In addition to these, water vapor, carbon dioxide, argon, and hydrogen are usually present. Other substances are sometimes found, depending upon local conditions. These are ammonia, oxides of nitrogen, sulphur dioxide, hydrogen sulphide, salts, dust, and bacteria.

Nitrogen is the most abundant compound present in the air, being about 77.5% by volume and 75.5% by weight.

Oxygen is next in quantity, nearly 20.75% by volume and 23.2% by weight. Argon and other inert gases make another one per cent and water vapor and carbon dioxide constitute the remaining percentage. The *constant ingredients* are nitrogen, oxygen, argon, helium, hydrogen, and some rare gases. The *variable ingredients* are water vapor, carbon dioxide, and the other gases and substances mentioned.

Nitrogen. Nitrogen is the largest and least variable component of the air. Although so abundant, it really plays very little part in the processes going on in the atmosphere. Indeed its chief function may be said to be that of a *diluent* for the oxygen of the air. In other words it moderates the excessive activities of the latter element and helps prevent conflagrations from being widespread. Nitrogen has always been in the atmosphere. Little by by little this element has been incorporated into the soil by different agencies, such as bacterial life, plants, and electro-chemical fixation. Considerable nitrogen is being removed from the air at the present time. Electrical thunderstorms also carry nitrogen to the earth and the electricity generated by great waterfalls is being used to accomplish the same result. It is seen, therefore, that nitrogen is being taken out of the air and put into the soil. On the other hand, there are certain processes which tend to return nitrogen to its vast storehouse. Such are a loss of this element from soils and decaying organic matter by *denitrification,* and a return of nitrogen in the processes of combustion.

Oxygen. Oxygen also was probably present in the primeval atmosphere and that portion which was left after the earth's crust was fully oxidized and formed is the source of the present atmospheric oxygen. It is the most active constituent of the air. The air is calculated to contain over two and one half million billions of pounds of oxygen. The yearly consumption of this by respiration is two and one quarter billions of pounds. It would require over one hundred years to use up one ten-thousandth of the total supply of oxygen in this way. This element is removed from the atmosphere by a variety of processes. The breathing of animals, known as respiration, the burning of fuels, called combustion, the true respiration of plants, bacterial processes, oxidation of minerals, and other similar steps are ways in which oxygen is taken out of the air. Oxygen is returned to the air principally by the process of photosynthesis of plants. On account of the large number of oxidation processes taking place, the proportion of the element is subject to local variations. These are not so great, however, as might be expected, on account of the influence of diffusion, wind, and the compensating action of vegetation. In cities and over marshy places the amount of oxygen is generally found to be slightly less than in the open country or over the sea. It is thought that the air is being slowly depleted of its oxygen, but the action is so slow that it cannot be detected at the present time.

Water Vapor. Water vapor is an exceedingly variable constituent of the air. The amount depends principally upon the temperature and proximity to bodies of water. With either increase of temperature or nearness to bodies of water, the quantity of water vapor in the air increases. At 0°C. 5.4 grams of vapor are contained in one cubic meter of saturated air. At 10° 9.7 grams, at 20° 17.1 grams and at 30° 30 grams. If only 0.4 of the water is in the air that the latter can hold at any given temperature, the air is dry. If 0.8 of the maximum capacity of water is in the air, the latter seems *moist, or humid.* In such cases the presence of so much water in the air makes conditions very oppressive for animals and human beings. The expressions *muggy* and *close* are frequently used to indicate this condition. If the temperature is low and the atmosphere near the saturation point, the cold is stinging and persons feel it more strongly than if the air were relatively dry. This explains why a temperature of 0° or 10°F. below zero near the seacoast or the great lakes affects a person far more than 20° or 30°F. below zero farther north or inland where there is very little moisture in the air. If the temperature is high, as in the summer time, and the air is near its *saturation capacity*, the heat is felt by animals far more than on a dry warm day, because the evaporation of water from the animal body by perspiration is prevented. This loss of water from the animal body lowers the temperature of the body and is nature's method for equalizing the temperature outside and in the body. Air is saturated with water vapor or at the *dew point* when the slightest reduction of temperature or increase of pressure causes precipitation of some of the water.

The cycle of water has already been discussed. We will consider in this connection only the relation of the water vapor to the other constituents of the air. When the condensation of the water vapor in the atmosphere has reached the point where drops of water are formed, these fall to the ground as rain. The rain carries with it mechanically the dirt and bacterial impurities of the air. It also carries in solution some of all the gases of the atmosphere. The kind and amount of these substances will of course vary depending upon the particular locality of the rainfall. That these quantities are important has been proved in many localities, notably at the Rothamsted experiment station in England. The following amounts of materials were found to be precipitated along with rain as an average per acre per year for a period of years. Nitric oxide from 1.0 to 2.5 lbs., sulphur trioxide 17.25 lbs., ammonia 1.0 to 5.0 lbs., chlorine in combination 14.0 to 116.0 lbs., and common salt 24.0 to 37.0 lbs. It can be quite readily understood that the constant fall of these substances, small as they may be for any one year, will in time be considerable.

Some of their effects are quite common and might be mentioned in this connection. It is well known that grass and crops in general show a more luxuriant growth and have a healthier color after a thunderstorm than after an ordinary rainfall. The reason is that oxides of nitrogen have been formed by the electrical disturbances during the thunderstorm and lightning and these compounds have been brought to earth by the rain. Nitrogen in this form is a very active fertilizer and stimulates the growth of the vegetation. In the region of smelters where considerable sulphur dioxide is given off into the atmosphere, this substance is carried by the prevailing winds in certain directions and in time is brought to the earth's surface by rainfall. Wherever the dissolved gases come in contact with vegetation they act as poisons and all plant life is killed. As the natural vegetation dies, there is nothing to hold the soil particles together and erosion results. Moreover, the ground has a characteristic light color indicating that the gases in the rain water are dissolving out the easily soluble minerals and leaving practically only quartz or those rock particles that are rather difficult to dissolve. Another well known effect of atmospheric gases upon plant life is seen in the household. It is sometimes impossible to grow house plants successfully since the products from the combustion of illuminating or fuel gas are fatal to them.

From a consideration of all these points it can be readily seen that rainfall or water vapor acts as a purifier of the atmosphere. The moisture of the air is very serviceable as one stage in the cycle of water where rainfall is the important succeeding stage. As already stated, water vapor also serves to regulate climatic conditions and to retain the heat rays of the sun upon the earth's surface.

Carbon Dioxide. This substance is present in the air to a *comparatively small extent* when the other constituents just mentioned are considered. It is, however, one of the most important substances present there and serves a number of vital functions. Life as it now exists on the earth is absolutely dependent upon the carbon dioxide of the air. If it were removed the earth would very soon become a barren waste. In the atmosphere of the open country or over the sea, carbon dioxide amounts to about 0.03% by volume, in other words about three parts per ten thousand. Over cities, where considerable fuel is consumed, the percentage of carbon dioxide increases to 0.06%, and in crowded rooms the quantity may be six or eight times as high as the last figure. If the proportion of carbon dioxide is over 0.06%, the air is said to be foul, not so much on account of the carbon dioxide itself as on account of the decaying organic matter which is exhaled along with it from the lungs of human beings. The quantity of carbon dioxide in the atmosphere of a room thus serves as an index to the amount of poisonous material present.

It is estimated that the total amount of carbon dioxide present in the atmosphere over an acre of land is about thirty tons. Evidently, then, the relatively small amount of 0.03% by volume means considerable when applied to a rather large amount of air. The total amount of this gas in the atmosphere of the globe is estimated to weigh over 5,000 billions of tons.

Carbon dioxide enters the atmosphere in numerous ways. The respiration of animals, the burning of fuels, the escape of underground gases, volcanic gases, the decomposition of organic matter, all serve to continually reinforce the supply of this ingredient. On the other hand, nature has provided certain means by which the gas is removed from the air, and the quantity never increases, except under local conditions and for a temporary period. It should, however, be stated that the proportion of carbon dioxide is greater during the night than during the daytime over the land. It has been shown that during the day there are 2.78 parts per ten thousand while at night there are 2.82 parts. Over the sea this daily variation cannot be detected.

The rainfall removes considerable carbon dioxide in solution. Growing plants secure all their carbon from atmospheric carbon dioxide. This is the chief process which tends to diminish its quantity. The extent of this removal of carbon dioxide from the air by plants is simply enormous. About half of the dry matter of plants consists of carbon all of which comes from the atmosphere. An average acre crop of mangels abstracts from the air, before reaching maturity, about 3,500 pounds of carbon, which represents the carbon dioxide in a 200-foot layer of air over some 180 acres.

The amount of carbon dioxide in the atmosphere is continually being affected by the addition and removal of the gas in the different ways indicated. The two processes approximately balance each other, and, as far as can be learned by analysis, the proportion of the gas in the atmosphere is apparently uniform within the limits stated.

Ammonia. Ammonia is one of the ordinary products of the decay and decomposition of organic matter. Waste animal matter evolves ammonia gas more or less quickly. The pungent odor in the vicinity of manure piles and stables is characteristic of ammonia. This gas diffuses through the atmosphere and is returned to the earth *in the rainfall.* Since nitrogen in the form of ammonium salts is a plant food, it can readily be seen that this process is an important one to return nitrogen to active circulation and help plant growth. That the amount of nitrogen recovered for life processes is considerable has already been stated under the effect of rainfall upon atmospheric gases.

Less Important Constituents of the Air. Hydrogen exists in small quantities in the atmosphere. Some experiments made with the air of Paris show that 100 liters of it contain about 19 cubic centimeters of hydrogen.

Argon is a constituent which is next to nitrogen and oxygen both in constancy and total amount present. It is heavier than oxygen and is more soluble in water than nitrogen. But argon is almost without chemical activity.

Helium was known to be present in the atmosphere of the sun long before it was found on the earth. It occurs not only in the atmosphere but in a few minerals, springs, and a meteorite. It is probably less soluble in water than any other gas.

Ozone is present in the air in variable amounts, always very small. In towns and over marshes it is rarely found, because, if present, it would react very quickly with other substances and lose its own identity. It is most abundant during May and June, especially after severe thunderstorms or gales. It is doubtful whether its presence in the atmosphere has any beneficial effect upon persons breathing it, but it would seem that its presence proves that the air is free from oxidizable organic matter and micro-organisms.

Atmospheric Dust. It is a well known fact that there is usually dust in the atmosphere. This fine material of mineral, organic, or bacterial origin settles in a thin deposit over furniture and all parts of a building. Even though a house may not be in use, the dust is still present, finding its way into the building under the influence of drafts or wind currents. Dust storms and even sand storms are of frequent occurrence in certain parts of the globe. Generally the circulation of dust may not be of any great moment beyond the inconvenience of keeping a house with its contents clean; but in some instances it may result in *changes of great economic importance.* Disease is undoubtedly spread in this manner. In many cases the whole depth of tillable soil has been swept away by a violent wind storm. Sometimes sand carried by wind has even drilled its way through the glass panes of lighthouses and houses along the seashore. Probably every student is familiar with the effect of the wind in laying down dirt and soil against fences and uneven places in a field or road. There are vast areas of soils in the Mississippi valley and in parts of China which were formed by the wind. The general name aeolian is applied to such soils. Loessial and adobe soils are included under this head.

Micro-Organisms. These are most abundant in towns or wherever organic substances are undergoing decay. They are important, since they may spread disease, distribute yeasts and moulds which cause fermentation and decay, and scatter the particular organisms which are responsible for the fixation of atmospheric nitrogen.

Salts. In some instances large quantities of salts have been proved to be in the atmosphere. They are chiefly common salt which has been carried inland by the ocean breezes. The ocean fogs and the fine mists caused by the breaking of waves upon rocky coasts, contain much salt. In this finely divided form, such substances can be carried considerable distances by winds. The common dust of wind storms and especially the alkali dust from the arid plains contain salts. Though they may not be of any great moment they are worth mentioning, as they undoubtedly influence soil fertility.

The Air Is a Mixture. The proportions of the chief constant constituents of the air have been determined in many different localities. *They have been found to be practically the same everywhere.* This condition is certainly remarkable, but is undoubtedly the result of the *circulation of air* and the *rapid diffusion* of its gases. On account of the quite constant proportion of oxygen and nitrogen of the air, it might be supposed that the air is a compound. A number of considerations, however, prove that this is not so: (1) When proper quantities of oxygen and nitrogen are mixed, there is no evidence of union such as change of color, volume, or physical condition, evolution of heat, etc. (2) Liquid air has a different proportion of oxygen and nitrogen than normal air has. Moreover, liquid nitrogen can easily be separated from liquid oxygen, since it boils away first. (3) Normal air has about 21 volumes of oxygen and 78 volumes of nitrogen. But air which has been dissolved in water has 35 volumes of oxygen and 65 volumes of nitrogen. If the air were a compound, the proportion of gases ought to be the same in both cases.

NITROGEN

Introduction. Nitrogen is the chief constituent of the atmosphere by volume and by weight. It is one of the most essential elements of plant and animal life. Yet as a simple and elementary substance it is characterized by *extreme inactivity.* Its compounds are, on the other hand, sometimes *extremely active,* in fact dangerously so. Its relative inertness is indicated by the name *azote* which is sometimes used and means *non-life supporting.*

Distribution. Nitrogen occurs in nature in *both the free and the combined state.* In the free form it constitutes practically four fifths by volume and three quarters by weight of the atmosphere. The actual proportion is 77.5 parts per 100 by volume. In the combined condition nitrogen exists in *many compounds found in mineral, animal and vegetable matters.* The largest mineral deposit of nitrogen is found in Chile and Peru in the compound sodium nitrate, commonly called Chile saltpetre. Other deposits of the same material are reported for the peninsula of lower California and some other localities situated in a dry climate. Small deposits of ordinary saltpetre, niter, or potassium nitrate, are found in the earth in India. It is reported that accumulations of nitrates are gradually being formed in certain parts of Colorado. Fertile soils contain very small quantities of nitrates of potassium, sodium, and calcium. Nitrogen is also present in other forms in the soil.

Soft coal contains a small percentage of nitrogen, ranging from 0.5 to 2%. When this coal is heated in the process of preparing illuminating gas, the nitrogen is given off as ammonia and may be recovered as a by-product in the compound, ammonium sulphate.

In the vegetable kingdom nitrogen exists in a number of complex compounds. The most valuable constituents of foods, such as the gluten of wheat flour, and many medicinal substances, like quinine and morphine, contain nitrogen.

A great proportion of the matter of animal origin is nitrogenous. Egg albumin, the casein of milk, and the fibrin of meat are examples of food products which are valuable for their content of nitrogen. The human body contains 2.4% nitrogen.

Cycle of Nitrogen. The terrestrial supply of nitrogen may be looked upon as being in two portions. That in the atmosphere is called the inactive stock and that in plant and animal life and in mineral deposits is called the active stock. The quantity of nitrogen in the air is very great. This is not very active and does not readily combine with other elements to form compounds of nitrogen. During thunderstorms oxides of nitrogen may be formed from this source and these may be brought to the earth's surface by the rainfall. There are numerous kinds of bacteria which are capable of taking nitrogen from the air also. One of the most familiar examples of these is the class of bacteria that is actively associated with *leguminous plants*, as peas, beans, clover, alfalfa, etc. The nodules formed by these bacteria on the roots of such plants often contain over 5% of combined nitrogen which is afterward digested and absorbed by the roots of the plant. Some of this nitrogen is left in the soil after the plant dies. *In fact all the nitrogen present in the soil originally came from the atmosphere.* Nitrogen is taken out of the soil by plants and the latter are consumed by animals. When plants and animals die, they undergo decomposition by bacterial action and the nitrogen is again set free either as nitrogen or as simple compounds, such as ammonia and oxides of nitrogen. There is a gradual slow return of some of this nitrogen to the air by the rotting of organic matter, especially *denitrification*, and by the burning of fuels and other substances of vegetable or animal origin. The *cycle of nitrogen* is illustrated diagrammatically in Figure 20.

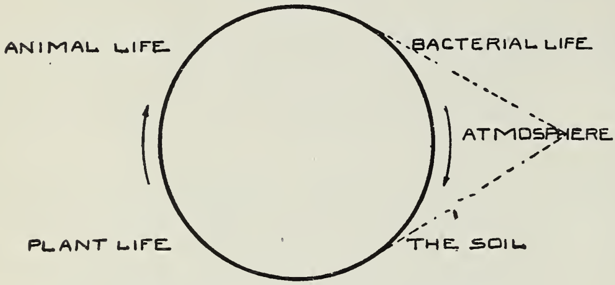


Figure 20.—The cycle of nitrogen.

Preparation. Nitrogen may be prepared from the atmosphere or a few of its compounds. It may be prepared from the air by first absorbing the other substances present, leaving the nitrogen. There are some elements, however, which are not removed by this method and they are mixed with the nitrogen resulting from the treatment. In order to carry on the process it is better to choose a substance which will combine with the oxygen and form a product not a gas. This facilitates the separation from the nitrogen. Phosphorus and copper are the substances most commonly used for this purpose.

(1) *By the action of phosphorus.* A small piece of phosphorus is placed in a dish upon a cork and floated in water. It is ignited by a hot wire and a large bottle is placed over it so as to confine the volume of air concerned in the experiment. The phosphorus combines with the oxygen of the air to form phosphorus pentoxide which is soluble in the water. The nitrogen is left unchanged. The water rises to take the place of the oxygen withdrawn by the reaction.

(2) *By the action of copper.* Figure 19, which shows the method of proving the relations by weight of the constituents of water, illustrates a simple device which can be used for the preparation of nitrogen. A current of air is slowly passed in at the left of the tube which contains a quantity of copper. The latter is heated and combines readily with the oxygen of the air. The nitrogen passes on and may be collected by displacement of water in bottles, as in the preparation of hydrogen and oxygen.

Nitrogen may also be prepared by decomposing certain of its compounds in such a way as to liberate the gas itself. If ammonium nitrite is heated, nitrogen and water vapor are the products. The gas can be collected in the usual manner over water. This method gives practically pure nitrogen. In fact the differences in the properties of the nitrogen prepared in this way and that from the atmosphere led to the discovery of the inert gases of the atmosphere.

Physical Properties. At ordinary temperatures nitrogen is a colorless, odorless, and tasteless gas. It is slightly lighter than the air, one liter weighing 1.25 grams. Nitrogen is only very slightly soluble in water (1.6 volumes in 100), much less than oxygen. It may be liquefied by lowering to -146°C. under 35 atmospheres of pressure and solidified by cooling to -214°C.

Chemical Properties. Under ordinary conditions nitrogen is extremely inactive. This is its most characteristic property. It neither burns nor does it support combustion. Neither does it directly enter into combination with other elements at ordinary temperatures. It may, though, combine with a few substances such as aluminium and magnesium, if brought into contact with them at a red heat. These compounds are called *nitrides*, just as some oxygen compounds are called oxides. Under the influence of electrical discharges nitrogen combines with hydrogen; also under the same conditions it combines with oxygen. On account of this property we are able at the present time to take nitrogen out of the air by artificial means.

Nitrogen is not poisonous to animals, for they constantly inhale it from the atmosphere; but life would be impossible in pure nitrogen, because it would exclude oxygen which is necessary for respiration. Nitrogen enters into the composition of a large number of compounds. In direct contrast to the relative inactivity of the element itself, some of these compounds are active to a high degree. Nitroglycerine, for example, is highly explosive. Many nitrogenous animal and vegetable compounds decompose easily. Nitric acid and ammonia are both active and are much used in the laboratory and manufacturing processes.

Compounds of Nitrogen. Of the compounds of nitrogen, only a few will be considered. The two most important are ammonia and nitric acid.

Before these two compounds of nitrogen are studied, however, let us consider a few general terms that will be used very frequently from now on in the study of chemistry.

ACIDS, BASES, SALTS

Acids. Mention has been made several times of *acids*, especially under the topic of hydrogen. Can you recall the relation which was stated to exist between acids and the element hydrogen? As commonly understood there are at least four characteristics of substances designated by the general name of acid, though every acid does not necessarily possess all these properties. They are (1) a sour taste, (2) their water solutions turn blue litmus red, (3) they react with metals with the liberation of hydrogen, and (4) they combine with bases to form salts.

Besides the chemical acids of the laboratory and commerce, such as hydrochloric, nitric, and sulphuric acids, there are a number of common substances which contain acids. A few examples are fruit juices, vinegar, sour milk, and rancid butter. Acids may contain one or more hydrogen atoms which can be replaced by a metal; those with one hydrogen atom are called *monobasic,* those with two hydrogen atoms are known as *dibasic* and so on.

Bases. The name *base* is applied to those substances which unite with acids and form salts. They are either hydroxides or oxides of the metals. The strong bases, which are very soluble in water, such as the hydroxides of sodium, potassium, and calcium, are called *alkalies.* The name *caustic* is often applied to them on account of their corrosive action. The alkalies, or those bases which are soluble in water, turn red litmus blue and have a bitter or acrid taste. Substances which affect litmus in this way are said to have an alkaline reaction. Alkalies contain the *hydroxyl* group, or radicle, OH. If one radicle is present, they are called *monacid*; if two radicles, *diacid,* etc.

Salts. *A salt* is the main product of the interaction of an acid and an alkali or base. Water is another product of such a reaction. This process is commonly known as *neutralization,* and salts are generally *neutral* in reaction to litmus. A salt is composed of the metal of the base and the elements of the acid other than the hydrogen. Salts may also be formed in other ways, as, for example, the action of an acid upon a metal, or by the action of an acid upon a carbonate.

Some examples of reactions involved in the formation of salts are shown by the following equations.

$$\begin{gathered}
HCl + NaOH \rightarrow NaCl + H_2O \\
H_2SO_4 + 2\ KOH \rightarrow K_2SO_4 + 2\ H_2O \\
2\ HNO_3 + Ca(OH)_2 \rightarrow Ca(NO_3)_2 + 2\ H_2O \\
Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2 \\
2\ HCl + CaCO_3 \rightarrow CaCl_2 + CO_2 + H_2O
\end{gathered}$$

Salts in which all the hydrogen atoms are replaced by metals are called *normal salts.* If some of the hydrogen is not replaced, they are called *acid salts.* When some of the hydroxyl, or OH radicles, of a base is not replaced, a *basic salt* results. Are there any examples of each of these different kinds of salts in the above equations? In addition to the formation of a salt in neutralization, what compound seems to be characteristic of that reaction?

AMMONIA, NH_3

Distribution. Ammonia is found in nature in both the free and combined forms. Free ammonia occurs only in small quantities in the atmosphere, part of this supply being given off from decaying organic matter and part being produced by discharges of electricity during rainstorms. Some combined ammonia is found in the air and in plant and animal products.

Preparation. Ammonia may be prepared by heating ammonium compounds with or without a strong base, as slaked lime. The simplest method for laboratory purposes is to heat a small portion of the concentrated ammonium hydroxide, commonly called *ammonia water.* Another method is to heat a mixture of equal parts of slaked lime and an ammonium compound, as ammonium chloride.

$$2\,NH_4Cl + Ca(OH)_2 \rightarrow 2\,NH_3 + 2\,H_2O + CaCl_2$$

The ammonia of commerce, however, is a by-product of the dry distillation of organic matter, such as bones, soft coal, etc. In this way the nitrogen is recovered in the form of ammonia from waste animal matter and from the manufacture of illuminating gas. Since the gas is very soluble in water, it is either collected over mercury or by upward displacement of air. It can be dried over quicklime.

Physical Properties. Ammonia is a colorless gas with a strong pungent odor and taste. It is 0.59 times as heavy as the air, one liter under standard conditions weighing 0.762 gram. It is very soluble in water, one cubic centimeter of water at standard conditions absorbing 1,146 cubic centimeters of the gas. Water solutions of the gas have a lower specific gravity than water itself, the more gas dissolved, the lower the density. All the ammonia can be expelled by heating. Under favorable conditions charcoal absorbs 90 times its volume of ammonia gas. The great solubility of ammonia in water is plainly shown by the so-called *ammonia fountain.* Figure 21. The flask A is filled with dry ammonia gas. The tube B with a stopper is fitted into the flask and the lower end placed in a volume of water containing a few drops of litmus solution. The action can be started by blowing a little water up from the lower end of the tube B. The ammonia dissolves in the water so rapidly that a vacuum is formed in the flask and more water is forced up by atmospheric pressure. The action is maintained until all the ammonia is dissolved. If the upper end of the tube is drawn to a rather fine opening, the water rushes up with such force that it is sprayed in all directions as it hits the bottom of the flask. The ammonia solution turns the litmus blue.

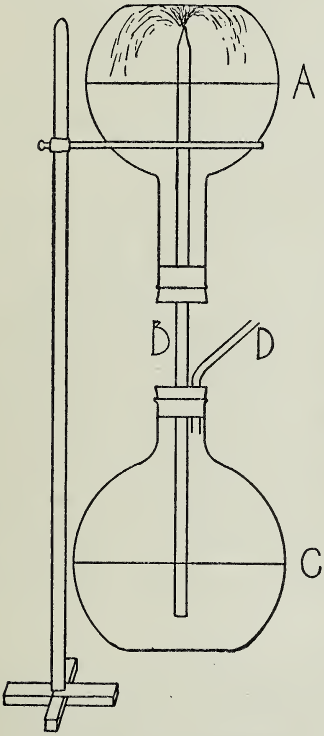


Figure 21.—The ammonia fountain.

Ammonia is an example of a gas that can be liquefied by pressure at a temperature only slightly below zero. Liquid ammonia is 0.6 times as heavy as water, boils at − 40°C. and freezes at − 75°C. Its greatest usefulness is as a refrigerating agent and for the manufacture of artificial ice. The ammonia is continually passed through a change from the liquid to the gaseous state and from the gaseous to the liquid form. The gas is liquefied by compression and the heat thus liberated removed by flowing water which surrounds the pipes. The liquid then passes into other pipes immersed in calcium chloride brine and is allowed to evaporate, the gas returning to the compressor. The heat necessary for this vaporization is taken from the brine which is partially frozen. The freezing mixture of ice and brine thus formed is then distributed to the localities to be cooled.

The ammonia and brine remain in their respective systems of pipes and are used over and over again. There is some loss of ammonia, however, by the process. Liquid sulphur dioxide and liquid carbon dioxide may also be used to manufacture artificial ice in a similar manner.

Chemical Properties. Ammonia does not burn in the air, but it does burn in pure oxygen, forming water and nitrogen. It does not support combustion. Ammonia is a fairly active substance, though, and combines readily with chlorine, hydrochloric acid, and other acids. Its water solution turns red litmus paper blue and is, therefore, an alkali. With acids ammonia unites directly and forms a series of ammonium compounds. If a bottle of ammonium hydroxide and one of hydrochloric acid are unstoppered and placed side by side dense fumes of ammonium chloride are formed.

$$NH_4OH + HCl \rightarrow NH_4Cl + H_2O$$

Composition of Ammonia. It is possible to take advantage of the reaction of chlorine with ammonia to prove the *volumetric composition of ammonia.* The tube shown in Figure 22 is filled with saturated salt solution which is then displaced with chlorine gas. After the stopcock is closed, concentrated ammonia water is run into the chlorine drop by drop. The hydrogen and the chlorine react quickly forming hydrochloric acid, and the nitrogen is left as a gas. The experiment is completed by allowing dilute sulphuric acid to be drawn into the tube to take the place of the hydrogen and chlorine which have combined. The volume of the nitrogen remaining is one third that of the original chlorine. As hydrogen and chlorine combine in equal parts (see later) the volume of nitrogen is to the volume of chlorine as one is to three, and the volume of nitrogen is to the volume of hydrogen as one is to three.

NITRIC ACID, HNO_3

Preparation. Nitric acid may be prepared by heating sodium nitrate or any other nitrate with sulphuric acid in a retort. The nitric acid is volatile and may be condensed as it distills over.

$NaNO_3 + H_2SO_4 \rightarrow HNO_3 + HNaSO_4$. See Figure 23. Another commercial process is the direct union of atmospheric nitrogen and oxygen by means of an electrical discharge. The nitrogen peroxide, NO_2, thus formed is dissolved in water giving nitric acid, and nitric oxide, NO, which unites with the oxygen of the air to give more nitrogen peroxide.

Physical Properties. The *anhydrous* (without water) acid is a thick colorless oil with a specific gravity of 1.56. It is easily decomposed by heat and light, and solutions consequently become brown upon standing.

Chemical Properties. This substance has the properties of an acid and is also a powerful oxidizing agent. These two characteristics should be kept clearly in mind. Whereas metals usually liberate hydrogen from acids, this reaction occurs with nitric acid in only a few cases. The hydrogen reduces the nitric acid just as rapidly as it is set free, and water, nitric oxide, and even ammonia are formed.

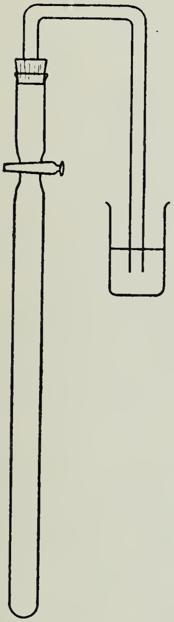


Figure 22. — Apparatus to prove the volumetric composition of ammonia gas.

When one volume of nitric acid is mixed with three volumes of hydrochloric acid, they form what is known as *aqua regia*, a liquid which dissolves gold, the king of metals. The action of this liquid is due to the liberation of chlorine which acts strongly upon gold and platinum.

Nitric acid also vigorously oxidizes other materials than metals; for example, sulphur is converted into sulphuric acid, a piece of glowing carbon may be completely burned in concentrated nitric acid, and organic dyes are changed to colorless bodies. This acid affects protein substances in a characteristic manner, namely, it turns them yellow, a reaction commonly called *xantho-proteic.*

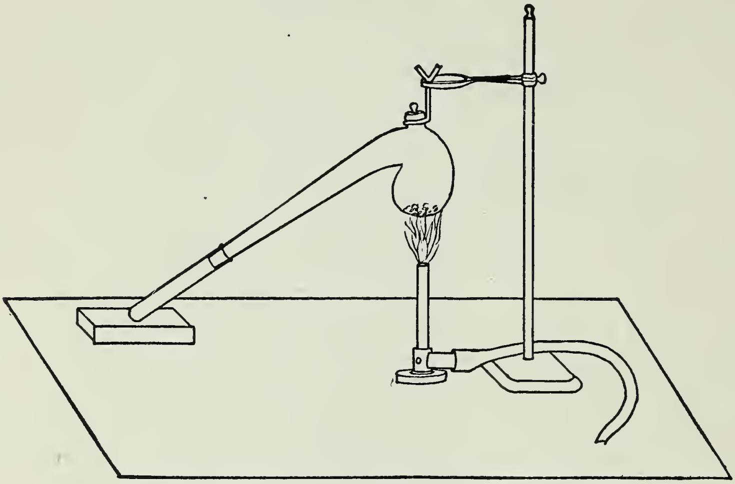


Figure 23.—The preparation of nitric acid.

Usefulness. Nitric acid and nitrates have a number of important industrial applications. The acid is used for the manufacture of nitrobenzene for perfume, nitroglycerine and nitro-cellulose or guncotton for explosives and collodion and celluloid prepared from nitro-cellulose. The salts of nitric acid are also used in the manufacture of explosives and for the preservation of meats.

OXIDES OF NITROGEN

Nitrogen forms a series of five oxides, the names and the formulas of which are as follows; nitrous oxide, N_2O, nitric oxide, N_2O_2 (or NO), nitrogen trioxide, N_2O_3, nitrogen tetroxide, or nitrogen peroxide, N_2O_4 (or NO_2), nitrogen pentoxide, N_2O_5. Of these only nitrous oxide, nitric oxide and nitrogen peroxide will be considered.

Nitric Oxide. This substance is prepared by the action of dilute nitric acid upon copper. It is a colorless gas with the characteristic property of combining directly with oxygen to form nitrogen peroxide, NO_2. It supports the combustion of phosphorus but not of sulphur and organic matter.

Nitrogen Peroxide. This compound is liberated by heating nitrates, except those of sodium, potassium, and ammonium. It is a reddish brown gas and may be easily liquefied. It parts with oxygen more readily than nitric oxide and is a powerful oxidizing agent.

Nitrous Oxide is the substance called *laughing gas.* Besides its characteristic property of an *anaesthetic* it also supports combustion, but in a more limited manner than oxygen.

The five oxides of nitrogen are an excellent illustration of the law of multiple proportions. This law states that, if two elements unite in more than one proportion, the quantities of one of these elements, united with identical amounts of the other, form simple ratios to one another in integral numbers. In the examples cited, the amounts of the oxygen which are united with a constant amount of nitrogen stand in the ratio of 1: 2: 3: 4: 5.

SUMMARY

The atmosphere is a mixture of a number of gases. As such it is responsible for a great many changes in nature on account of the different properties of its constituents. Nitrogen is the chief ingredient and is important for plant and animal life. Oxygen is next in abundance and it is from this source that the element is obtained for the common oxidation processes. Water vapor is a variable constituent, but is the cause of many far-reaching changes in the earth's surface. Carbon dioxide is also variable and comparatively small in quantity.

It is from this source, however, that plants obtain the carbon necessary for their growth. The other ingredients of the air are of less importance.

Nitrogen is a most important element. It exists in both the free and the combined form in nature. Though itself inert, its compounds are very active chemically. The common explosives either contain, or are prepared by the use of nitric acid or nitrates. Ammonia and nitric acid are two compounds of nitrogen which have important applications in commerce and industry. As nitrogen is an essential element of plant and animal life, its compounds are important in this connection. Other special uses of ammonia are as a refrigerating and cleansing agent; of nitric acid and nitrates, are as laboratory reagents for oxidizing reactions.

QUESTIONS

1. Why are the variable constituents of the atmosphere found in different proportions?
2. State the amount, source, and function of the following constituents of the atmosphere: carbon dioxide, ammonia, and water.
3. If it is possible to show that air is made up of two or more kinds of matter, how can the relative proportion of these be proved?
4. Is there any difference between heating matter in the air and without air? Give examples.
5. When oxygen and nitrogen are mixed in the proportion in which they exist in the atmosphere, heat is neither evolved nor absorbed by the process. What important point does this suggest?
6. What is the relation of the oxygen of the air to respiration?
7. Compare the breathing and burning processes. How are they affected by ordinary air, by oxygen and by ammonia?
8. In what respects does oxygen differ from nitrogen?
9. How would you distinguish between oxygen, hydrogen, and nitrogen?
10. Compare the activity of nitrogen with that of its compounds.
11. Discuss the circulation of the element nitrogen in nature.
12. Why are so few mineral compounds of nitrogen found in nature?
13. Why has it become necessary to devote so much attention to the artificial production of fertilizers containing nitrogen?
14. Predict the reaction to litmus of acid phosphate, sour bread, tart preserves and pickles.
15. Identify the following materials from their description: (a) A gas, lighter than the air, colorless, odorless, tasteless, does not burn nor support combustion, active only at very high temperatures. (b) A gas, heavier than the air, colorless, but has odor and taste, does not support combustion nor burn, but is active, forming a colored gas when coming in contact with the air.

CHAPTER IV

SOME OTHER NON-METALS

CHLORINE

Introduction. As an essential constituent of common salt and other compounds of importance to civilization, the substance chlorine is of great value. It is an *exceedingly active* substance and, therefore, *never found free* in nature.

Distribution. Compounds of chlorine are widely distributed in nature. Usually chlorine occurs in combination with metals as chlorides, of which sodium chloride, potassium chloride, and magnesium chloride are the most abundant. Nearly all salt water contains these substances, the sodium chloride predominating. Large salt beds are found in many parts of the world. Common salt, or sodium chloride, is the chief compound and source of chlorine.

Preparation. Chlorine may be prepared in a number of ways. The chemical method is essentially liberating chlorine from hydrochloric acid by an *oxidizing process.* It is

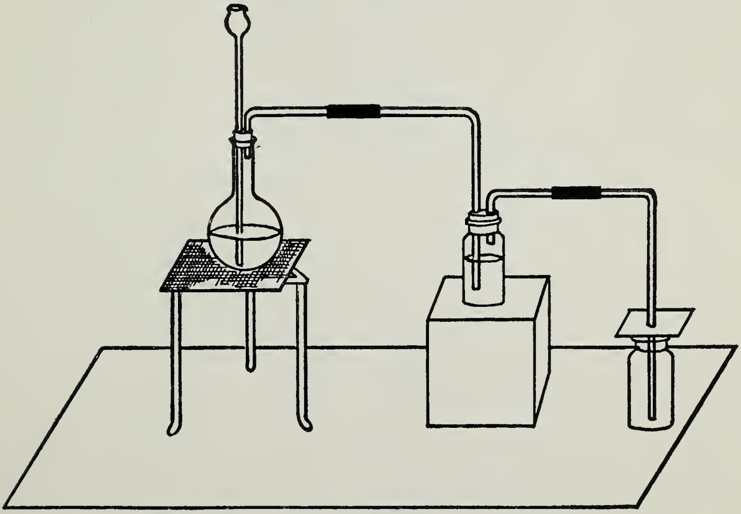


Figure 24.—The preparation of chlorine.

usually accomplished by bringing hydrochloric acid and manganese dioxide together in a suitable apparatus, and warming to facilitate the reaction. As the gas is soluble in water and heavier than the air, it is collected by downward displacement of air.

Figure 24 illustrates the apparatus for preparing chlorine. The manganese dioxide is placed in the flask and hydrochloric acid added through the thistle tube. By gently warming with a burner the chlorine is liberated and may be passed through the bottle which contains water to remove any hydrochloric acid which might contaminate the chlorine. The latter is then passed into a bottle which contains only air. After the bottle is filled, the gas can be tested in order to learn its chemical properties. The following is the equation for the reaction:

$$MnO_2 + 4\ HCl \rightarrow 2\ H_2O + MnCl_2 + Cl_2.$$

Chlorine may also be liberated by the *electrolysis of chlorides.* In the manufacture of caustic soda from sodium chloride chlorine is evolved at the anode. A great deal of the chlorine required in the chemical industries is made in this manner. Electrolysis of hydrochloric acid solution gives chlorine at one pole and hydrogen at the other.

Physical Properties. Chlorine is a greenish yellow gas, with a peculiar, very pungent, suffocating odor. It has a very irritating effect upon the throat and lungs. Small quantities produce all the symptoms of a hard cold and sore throat. Larger quantities may cause serious and even fatal action. It is nearly 2½ times as heavy as the air, 1 liter weighing 3.22 grams. Three volumes of the gas dissolve in one volume of water under ordinary conditions. Chlorine is readily liquefied by a pressure of six atmospheres at 0°C. It forms a yellowish liquid which solidifies at −102°C.

Chemical Properties. Chlorine is one of the most active of all the chemical elements. Its effect may be classified somewhat as follows: (1) *Action upon the metals.* Many metals combine directly with chlorine, especially when hot. Gold and silver are quickly tarnished by the gas. Powdered antimony reacts immediately, giving off much light and heat. Both copper foil and sodium, if heated and dropped into chlorine, burn brilliantly. Chlorides of the respective metals are produced by all these reactions.

$$Na_2 + Cl_2 \rightarrow 2\ NaCl$$

(2) *Action on non-metals.* Many of the non-metals combine with chlorine. Phosphorus burns in a current of the gas. (3) *Action on hydrogen.* Chlorine has a strong affinity for free hydrogen, uniting with it to form hydrochloric acid. A jet of burning hydrogen continues to burn when introduced into a jar of chlorine, giving a somewhat luminous flame. A mixture of the two gases explodes violently when a spark is passed through it or when it is exposed to bright sunlight. In the latter case it is the light and not the heat which starts the action.

$$H_2 + Cl_2 \rightarrow 2\ HCl$$

(4) *Action on substances containing hydrogen.* Chlorine often removes hydrogen from compounds of the latter. If chlorine is passed into hydrogen sulphide water, sulphur is precipitated and hydrochloric acid is formed. Water is decomposed by chlorine in the sunlight and oxygen is liberated.

$$H_2O + Cl_2 \rightarrow 2\ HCl + O$$

The attraction of chlorine for combined hydrogen is very strikingly seen in the action of chlorine upon turpentine, which is composed of hydrogen and carbon. If a strip of paper is moistened with warm turpentine and lowered into a jar of chlorine, there is an immediate reaction. A black deposit of carbon is formed and dense fumes of hydrochloric acid appear. (5) *Bleaching action.* When colored substances are moistened with water and exposed to the action of chlorine, the chlorine reacts with the water as stated above and liberates oxygen. This oxygen is very active, far more active than pure oxygen, and is said to be in the *nascent state.* The oxygen oxidizes the color substance and converts it to a colorless compound. That the moisture is necessary for the reaction is proved by subjecting colored materials to dry chlorine gas. No changes follow. (6) *Disinfecting action.* Chlorine has marked germicidal properties. Both the free element and compounds from which it can be readily liberated are used as disinfectants. *Chlorine water,* a solution of chlorine in water, is a powerful bleaching agent and disinfectant. Chloride of lime, *bleaching powder,* is also a bleaching and disinfecting agent.

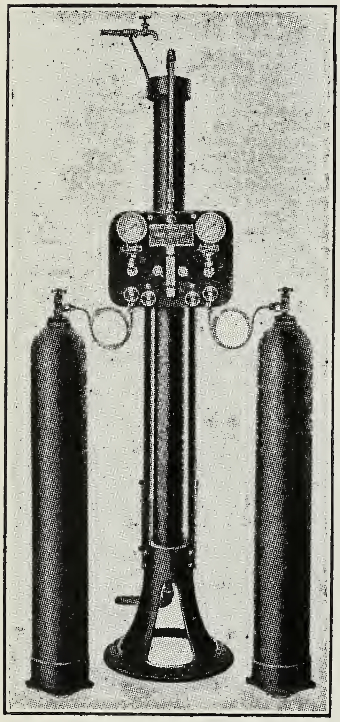


Figure 25.—The purification of water by chlorine.

In Figure 25 is shown an arrangement for the purification of water by liquid chlorine. The two cylinders contain the liquid which under reduced pressure becomes a gas. The latter is conducted up through a tube made of resistant stoneware. In this way it comes in contact with a very small amount of water in the form of a spray. The chlorine water produced passes out of the bottom of the tower and is conducted to the water or sewage to be treated. It has an instantaneous action upon bacteria and other oxidizable materials. Water thus treated is said to have no disagreeable odor or taste and the process is claimed to be far superior to the ordinary hypochlorite or bleaching powder method.

Hydrochloric Acid (HCl). This substance is prepared by the action of sulphuric acid upon sodium chloride. The dry salt is placed in a flask with a funnel tube and an exit tube, the sulphuric acid added and the flask gently warmed. The hydrochloric acid is rapidly given off and collected in bottles by displacement of air. The same apparatus (Figure 24) that is used for the preparation of chlorine can be utilized for making hydrochloric acid. The wash bottle should, however, be omitted from the arrangement. The equation for the reaction is

$$2\,NaCl + H_2SO_4 \rightarrow 2\,HCl + Na_2SO_4.$$

This process is one stage of the old Leblanc method for preparing sodium carbonate from sodium chloride. Another method by which hydrochloric acid may be prepared is the combining of hydrogen and chlorine gases by an electric spark or a flame.

Physical Properties. Hydrochloric acid is a colorless gas, has a sour, biting taste, and a pungent odor. It causes an irritating effect upon the mucous membranes of the eyes, nose, and throat. It is heavier than the air, 1.26 density, and is very soluble in water. In fact, it fumes in the air, since it condenses atmospheric water to drops. The fumes are really minute droplets of an aqueous solution of hydrochloric acid gas. One volume of water dissolves about 500 volumes of hydrochloric acid gas under ordinary conditions. The most concentrated solution of hydrochloric acid has a density of 1.20 and contains 40% hydrochloric acid gas. The pure acid is colorless, but the commercial acid, *muriatic acid,* is yellow on account of the presence of impurities, such as chloride of iron. On boiling a solution of hydrochloric acid, the gas will escape until the liquid has 20% by weight of hydrochloric acid gas. If the solution is weaker than this, water is driven off by boiling until the concentration of 20% is reached. In both cases the liquid remaining distills over unchanged at that point. Hydrochloric acid gas is liquefied at 0°C. under a pressure of 28 atmospheres. A colorless liquid is formed which is not very active chemically. It boils at $-80°$ and solidifies at $-113°$. The water solution of hydrochloric acid is the usual form in which the compound is met in the laboratory. It is far more convenient and more active than the gaseous form.

Chemical Properties. Some of the most important chemical properties of hydrochloric acid are the following: (1) *Action as an acid.* The water solution of hydrochloric acid has strong acid properties. In fact, it is one of the strongest acids. It reacts with bases to form chlorides and water. It is a common laboratory reagent. (2) *Relation to combustion.* Hydrochloric acid is not readily decomposed, it does not burn, nor does it support burning. (3) *Action with oxidizing agents.* Hydrochloric acid is oxidized under some conditions with the liberation of chlorine. The principle of this reaction has already been cited under the preparation of chlorine. When nitric acid and hydrochloric acid are mixed, the nitric acid oxidizes the hydrochloric acid, liberating chlorine and some other substances. This mixture is called *aqua regia* and is more powerful than either acid separately. Its strength is due to the action of the nascent chlorine it liberates.

$$3\,HCl + HNO_3 \rightarrow Cl_2 + NOCl + 2\,H_2O$$

In the human stomach there is found a 0.3% solution of hydrochloric acid which aids in the digestion of the food.

Chlorides. The chlorides are salts of hydrochloric acid. All the metals form chlorides and many of them are very important compounds. Some of them are found in nature. All of them can be prepared by the general method of preparing salts.

Other Compounds of Chlorine. Two oxides of chlorine are known. This element combines with hydrogen and oxygen to form four different acids. They are all unstable and most of them cannot be prepared in the pure form.

Their salts are, however, easily prepared and some of them are very important for laboratory and commercial purposes.

Calcium Hypochlorite. One example of such a compound is calcium hypochlorite, $CaCl(OCl)$, often called bleaching powder, and incorrectly called chloride of lime. This substance is manufactured by the action of chlorine upon lime. The lime is carefully slaked with water to form calcium hydroxide and this is placed in a large absorption chamber. The chlorine, generated by the electrolysis of sodium chloride, is passed in at the top of the chamber and absorbed by the lime as it settles to the bottom of the chamber. Bleaching powder is a yellowish white substance having a peculiar odor, which resembles that of chlorine. Upon exposure to the air it absorbs carbon dioxide and loses part of its chlorine. Acids liberate chlorine from the powder, the amount being from 30 to 38% in a good quality. When this reaction takes place in contact with cotton cloth, for example, the chlorine liberated has a powerful indirect oxidizing and bleaching effect upon the coloring matter or impurities of the cotton. Bleaching powder is, therefore, a very important chemical used in the textile industry.

The Halogens. There are three other elements which resemble chlorine in a general way in their properties. These elements are fluorine, bromine, and iodine. Because the compounds of three of them are found in sea water, the name *halogen*, or producer of sea salts, is applied to the group. None of these elements occurs free in nature. Their physical properties change gradually with increase of atomic weight. Their melting points and boiling points increase, their color grows more intense, and their form changes from gas to liquid to solid. Their chemical properties, though, seem to decrease with increase of atomic weight. That is, the activity of fluorine is far greater than that of iodine. This is shown very strikingly in the attraction of these elements for hydrogen. Fluorine combines with hydrogen explosively and abstracts hydrogen from its compounds actively. Iodine on the other hand does neither readily. While all these elements have important uses, chlorine is by far the most valuable to mankind. The chemistry of the other three is similar to that of chlorine, varying chiefly in degree.

SULPHUR

Introduction. Sulphur has been known from the earliest times, since it is widely distributed and occurs in large quantities in the uncombined form. Sulphur forms a number of important compounds, notably sulphuric acid, which is of great usefulness in numberless chemical industries.

Distribution. Sulphur occurs in nature in both the free and the combined forms. In the free condition it is obtained chiefly from Sicily, Mexico, Iceland, and Louisiana, where it is found largely in volcanic and spring deposits. In the combined form sulphur exists as sulphates and sulphides of many metals, as of iron, copper, calcium, and barium. Besides these minerals it is also a constituent of many animal and vegetable substances. For example, the yolk of an egg and plants of the cruciferae family contain large amounts of sulphur in combination.

Preparation. Natural sulphur is usually found mixed with much earthy material, from which it must be separated to prepare it for the market. The purification process consists of two stages. It is first heated on an inclined surface whereby the sulphur melts and flows away, leaving the impurities behind. Second, the partially purified sulphur is distilled from large iron retorts and is thus separated from less volatile impurities. The sulphur vapor is conducted into a cooling chamber of brickwork where it condenses. The fine crystalline powder first formed is called *flowers of sulphur.* As the temperature of the condensing chamber increases the sulphur collects as a liquid in it and is drawn off into cylindrical molds, the product being called *roll sulphur or brimstone.*

Physical Properties. Sulphur exists in several different physical forms, two crystalline and two amorphous. While some of their properties are common to all the forms, there are a number of properties that differ considerably. (1) Ordinary or *rhombic* sulphur is the natural and most stable form. All other forms revert to this at ordinary temperatures. It is yellow, odorless, tasteless, and melts at 114.5°C. It has a specific gravity of 2.06, is very soluble in carbon disulphide, but is insoluble in water. Roll sulphur or brimstone is composed of minute rhombic crystals. Above 96°C. rhombic sulphur changes to prismatic sulphur. (2) *Prismatic or monoclinic* sulphur is formed by the slow cooling of melted sulphur. As soon as a crust forms, it is broken and the liquid is poured off. The crystals are long, almost colorless needles, that melt at 119°C., dissolve in carbon disulphide, and have a specific gravity of 1.96. If kept below 96°C., they change in a few days to the rhombic form with evolution of heat. The temperature 96° is called the *transition point* of sulphur.

Two varieties of amorphous or non-crystalline sulphur can readily be obtained. *Plastic* sulphur is formed by heating ordinary sulphur and cooling it very suddenly. If the boiling sulphur is chilled suddenly by passing it into cold water, the product becomes an elastic, gummy, and non-crystallized substance. This becomes hard and brittle after several days and consists of rhombic sulphur which is soluble in carbon disulphide and an amorphous variety which is insoluble in carbon disulphide. *Amorphous* sulphur is the hardened form of the dark, viscous liquid. It was not given time to crystallize like the ordinary form on account of the sudden cooling. When kept below 96°C.

it changes slowly into rhombic sulphur with evolution of heat. Flowers of sulphur have a nucleus of rhombic crystals and an amorphous covering. These amorphous particles are insoluble in carbon disulphide and are left as a white residue when flowers of sulphur are treated with that chemical. Hence the name *white* sulphur is applied to the other amorphous variety.

The following changes ordinarily take place when sulphur is heated. At 114.5°C. ordinary sulphur becomes a thin yellow or straw colored liquid. As the temperature is raised above 160°C. this liquid becomes darker and thicker. At 230°C. it is almost black and is so thick that it can hardly be poured. At higher temperatures, above 300°C., it becomes thin again and at 445°C. it boils, giving a yellowish brown vapor. If allowed to cool slowly, these changes are repeated, but in the reverse order until ordinary sulphur is finally obtained.

Chemical Properties. Sulphur unites directly with many elements, especially the metals. These reactions occur more readily with increase of temperature, though there are some common illustrations of the action under ordinary conditions. Mercury combines with sulphur when the two are simply rubbed together in a mortar. Copper foil burns in sulphur vapor giving copper sulphide. Silverware may be blackened by the sulphur in eggs or by the sulphur compounds in illuminating gas. Silver coins which are carried in pockets are colored by the sulphur of the perspiration.

Sulphur unites readily with oxygen if heated, the action beginning at 260°C. It burns with a pale blue flame, forming sulphur dioxide. Small quantities of sulphur trioxide may also be produced by the process. Sulphur dioxide is an invisible gas which is characteristic of the well known odor of burning sulphur.

Uses of Sulphur. Sulphur has many important commercial uses. Rubber goods and vulcanite are made by heating together caoutchouc and sulphur. Match tips of the older style contain sulphur. Gunpowder is a mixture of carbon, sulphur, and saltpeter. Sulphur is used in the production of sulphur dioxide which is extensively used for bleaching and as a germicide. Sulphur is being used more and more as a material for controlling plant diseases, and, to a lesser extent, plant insect pests. Sulphuric acid, which is probably the most important chemical manufactured, is prepared from sulphur.

Compounds of Sulphur. Many compounds of importance to agriculture and commerce contain sulphur. The sulphides, next to the oxides, are the most common ores of the metals. Sulphur forms two important oxides, and in combination with hydrogen and oxygen, a number of acids.

Hydrogen sulphide, hydrosulphuric acid, H_2S. This compound is a colorless gas, with a very disagreeable odor, and a weak disagreeable taste. In the pure form it acts as a violent poison, and even when diluted largely with air produces headache, dizziness, and nausea. It is formed naturally by the decomposition of organic matter which contains sulphur. Since eggs contain this element and give rise to this gas when decaying, it is often said to be the gas with the odor of *rotten eggs*. Natural *sulphur waters* and the vapor issuing from volcanoes contain hydrogen sulphide.

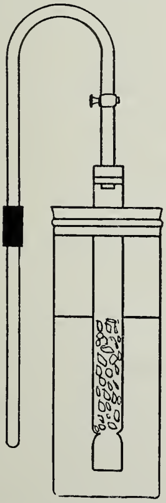


Figure 26.—Generator for hydrogen sulphide.

Hydrogen sulphide is prepared in the laboratory by treating ferrous sulphide with dilute hydrochloric or sulphuric acids. A convenient type of generator for hydrogen sulphide is shown in Figure 26. The inner tube contains the ferrous sulphide and is lowered into the bottle containing the acid. By turning the stopcock in the delivery tube the acid rises and attacks the sulphide of iron. The hydrogen sulphide is forced over by the pressure and can be collected in bottles by the downward displacement of air. Or, if it is desired to use the water solution of the substance, the gas can be passed directly into the water until the latter is saturated with it. The equation follows:

$$FeS + 2\,HCl \rightarrow H_2S + FeCl_2$$

The specific gravity of hydrogen sulphide gas is 1.18. Three volumes are soluble in one volume of water at ordinary temperatures. A jet of the gas completely burns in plenty of air, forming water and sulphur dioxide. If the air supply is limited, however, only the hydrogen of the compound burns. Hydrogen sulphide is easily broken down by heat into its elements. The aqueous solution is even decomposed by light and by the oxygen of the air into sulphur and water. Oxidizing agents affect the aqueous solution in the same way. On account of these facts, hydrogen sulphide is a strong reducing agent, taking oxygen away from many substances which contain it. It is also a weak acid. Its water solution turns blue litmus red and neutralizes bases, forming salts, called sulphides. It acts towards metals much as water. For example, if each of these substances is passed over heated iron in a tube, in the case of water iron oxide is formed and hydrogen is liberated; in the case of hydrogen sulphide iron sulphide is formed and hydrogen is liberated.

Most of the sulphides are insoluble in water and some are insoluble in acids. On account of this difference in the properties of the metallic sulphides, it is possible to separate the metals in the laboratory. Hydrogen sulphide is a convenient reagent for this purpose, the gas being passed directly into water solutions of the metallic compounds. This is one of the principal uses of hydrogen sulphide.

$$CuSO_4 + H_2S \rightarrow CuS + H_2SO_4$$

Carbon Disulphide, CS_2. This substance is formed by the direct union of carbon and sulphur. It can be affected by passing sulphur vapor over hot charcoal, or an electric furnace may be utilized to bring about the result. Pure carbon disulphide is a colorless liquid, having a pleasant odor. Commercial carbon disulphide is often yellow and has a very disagreeable odor. It is very inflammable, boiling at 47°C. and has a specific gravity of 1.27. The chief use of the compound is as a solvent for sulphur, caoutchouc, phosphorus, iodine, resins, and waxes. It is also used as an insecticide and for killing rodents.

Sulphur dioxide, SO_2. Sulphur dioxide is the gas produced by burning sulphur in air or in oxygen. It can also be prepared by oxidizing or roasting certain sulphides, notably the sulphide of iron called iron pyrites. This is one of the commercial methods used in the manufacture of sulphuric acid. Sulphur dioxide is commonly prepared in the laboratory by one of the following methods: by the action of acids upon sulphites, and by heating concentrated sulphuric acid with copper. In the latter process the sulphur dioxide is given off as a gas and copper sulphate and water are the other products. Sulphur dioxide occurs in nature in the gases issuing from volcanoes and dissolved in the water of many springs.

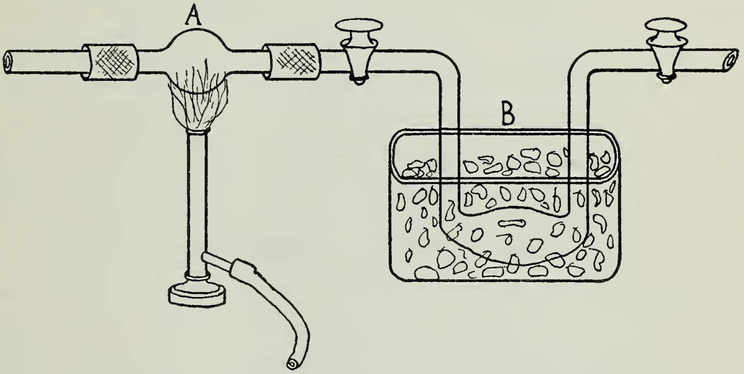


Figure 27.—The preparation of liquid sulphur dioxide.

Physical Properties. Sulphur dioxide is a colorless gas, with a peculiar, irritating odor, and a disagreeable taste.

It is 2.2 times as heavy as the air and very soluble in water, 80 volumes dissolving in 1 volume of water at 0°C. Sulphur dioxide can be obtained in the liquid form by passing it through a condensing tube surrounded by a freezing mixure of ice and salt. If a current of air is passed over sulphur heated in the bulb A and the products of the reaction are then cooled in the bulb B, the sulphur dioxide may be liquefied and collected. (See Figure 27.) Liquid sulphur dioxide is colorless and boils at −8°C. Since the evaporation of this substance absorbs much heat, it is often used as a refrigerating agent. Liquid sulphur dioxide can be purchased in strong bottles or sealed tins.

Chemical Properties. Sulphur dioxide is an active substance chemically. It combines with oxygen, both free and combined. Its most characteristic property is its ability to unite with water to form sulphurous acid. Sulphur dioxide is a very powerful bleaching and disinfecting agent. It is extremely valuable for bleaching silks, woolens, laces and straws which might be injured by chlorine. The sulphur dioxide probably combines with the coloring matter of these fabrics forming colorless compounds. The bleaching effect, however, may disappear in time. Sulphur dioxide has even been used to bleach and preserve food products, such as molasses, dried fruits, etc.; but this particular use is restricted by the food laws of many states. Sulphur dioxide is readily oxidized to sulphur trioxide and is in this way important for the preparation of sulphuric acid. The water solution of sulphur dioxide has the properties of a weak acid, and is called sulphurous acid. This substance is oxidized to sulphuric acid slowly by the air, but rapidly by oxidizing agents. When neutralized by bases, sulphurous acid forms a series of salts called sulphites. These also oxidize readily. Sulphurous acid has marked antiseptic properties and has the power of arresting fermentation. It is, therefore, used as a *preservative.*

Sulphur Trioxide, SO_3. Sulphur trioxide is a colorless liquid above 15°C. and boils at 46°C. Below 15°C. it is a white crystalline solid. In the air sulphur trioxide gives off dense choking fumes. It reacts with water violently causing intense heat and a hissing sound. Sulphur trioxide is prepared by oxidation of sulphur dioxide. A small amount may be formed by the simple burning of sulphur in the air or oxygen. When sulphur dioxide and oxygen are heated together some sulphur trioxide may be formed. The reaction is practically complete when a catalytic agent, as platinized asbestos, is used.

The term *catalytic, or contact agent,* is applied to a substance which aids a chemical reaction in some way. The process is called catalysis, or contact action. Apparently by its mere presence the catalytic agent increases the speed of a chemical change without itself suffering any permanent change. There are numerous examples of catalysis in chemistry. The effect of manganese dioxide upon potassium chlorate in the preparation of oxygen is a notable one. Do you recall just what this action is?

This is the principle of the contact process for the manufacture of sulphuric acid. The gases are mixed, heated and passed into the contact chamber where the sulphur trioxide is produced. This is then absorbed in water or dilute sulphuric acid, when it combines with the water and gives the acid. In the older or *chamber* process the oxidation of the sulphur dioxide takes place in the presence of water vapor. Steam, air, sulphur dioxide, and oxides of nitrogen are all used in this method. The nitric acid used in the process furnishes the nitric oxide, NO, which is successively oxidized by the air to nitrogen peroxide, NO_2, and reduced by the sulphur dioxide to nitric oxide, NO, continuously. The oxidation of the sulphur dioxide to sulphur trioxide is really caused by the oxygen of the air, but the nitric oxide is the catalytic agent or carrier necessary. The sulphuric acid made by this process is dilute, containing about 35% water. It is concentrated by evaporation, first in leaden pans, then in cast iron pans, and finally in glass, porcelain, or platinum vessels. The equation for both of these reactions is

$$SO_3+H_2O \rightarrow H_2SO_4.$$

Sulphuric Acid, H_2SO_4. *Properties.* Sulphuric acid is a thick, oily, colorless liquid, with a specific gravity of 1.84. Ordinary concentrated acid contains about 2% water and boils at 338°C. When diluted with water, much heat is evolved. To avoid the boiling and possible spattering of the liquid, the concentrated acid is always slowly added to the water in a small stream. *Never pour water into the acid.*

Sulphuric acid possesses a number of chemical properties which constitute it one of the most important chemical substances known. In dilute solution it has the properties typical of an *acid.* With oxides and bases it forms a series of salts called *sulphates.* Sulphuric acid contains a large amount of oxygen and is a good *oxidizing* agent. As it is made by the oxidation of sulphur dioxide to sulphur trioxide the reduction of the sulphur trioxide to sulphur dioxide is possible. This is accomplished by simply boiling or heating the acid in contact with sulphur, carbon, or copper. The action of the acid upon metals depends considerably upon the concentration of the acid. The dilute acid dissolves many metals, forming sulphates and liberating hydrogen. The concentrated acid, as just shown, in contact with metals usually liberates sulphur dioxide, because the hydrogen first produced reacts with the sulphuric acid itself and forms sulphurous acid, then sulphur dioxide and water.

Sulphuric acid has a very strong attraction for water. On account of this property it is used as a *drying agent* in the chemical laboratory. This *dehydrating* power not only applies to free water but also to the elements of water when combined with other elements, such as carbon. The action can be very readily shown by dipping a piece of wood into the strong acid. The wood chars, because the acid abstracts the hydrogen and oxygen and leaves the carbon. The boiling point of sulphuric acid is higher than that of almost any common acid. It is, therefore, largely used in the preparation of other acids.

Uses of Sulphuric Acid. This chemical, sometimes called *oil of vitriol,* is made in enormous quantities and is without doubt the most important artificial substance known to civilized man. Some of the valuable materials manufactured by the aid of the compound are nitroglycerine, nitric acid, hydrochloric acid, and coal tar products. Some important processes in which sulphuric acid is used are the refining of petroleum, the preparation of glucose, the manufacture of sodium carbonate by the Leblanc process, and the conversion of insoluble phosphates into available phosphate fertilizers. The use of sulphur as a *fungicide* may depend upon its slow oxidation by atmospheric means into sulphuric acid which destroys the mildew or other plant pest.

Sulphates. The salts of sulphuric acid are called sulphates. A number of these compounds have commercial uses, for example, copper sulphate, or blue vitriol, ferrous sulphate, or green vitriol, and magnesium sulphate, or Epsom salts. Many sulphates are found in nature, as gypsum, or calcium sulphate, and barytes, or barium sulphate. Since sulphuric acid is dibasic, there are both normal and acid salts. They can easily be prepared by a number of methods. The test for soluble sulphates is by means of barium chloride, in the presence of hydrochloric acid. Under these conditions a permanent white precipitate indicates sulphates.

PHOSPHORUS

Introduction. In a general way phosphorus resembles nitrogen in its properties. Both are non-metals, both have the same valencies, and both form a similar series of compounds, though the behavior of these compounds is often very different. Phosphorus is an element which has many uses in civilized life. It is of the greatest interest in agriculture, as it is probably the most important element to consider in connection with the maintenance of soil fertility.

Distribution. Phosphorus never occurs in nature in the free form, on account of its great chemical activity. It is the chief mineral constituent of the bones and teeth of animals, and is also found in other portions of the body, as the nerves and the brain. Phosphorus is a very important ingredient of the protoplasm of plants and, as the latter near maturity, the greater portion of this element is found in the seed or tuber. It occurs in soils to a certain extent, the amount depending upon the particular formation of the soil in question. The greatest source of phosphorus is in the natural deposits of calcium phosphate which are quite abundant and widely distributed. Some of the chief deposits occur in the southeastern part of the United States, Utah and Wyoming. Other deposits are reported in Russia and North Africa. Some of these phosphates are phosphorite and apatite. The former is found in beds of fossil bones, the other is composed of calcium phosphate and calcium fluoride. Such rock phosphates are very valuable and are extensively mined for use as fertilizers.

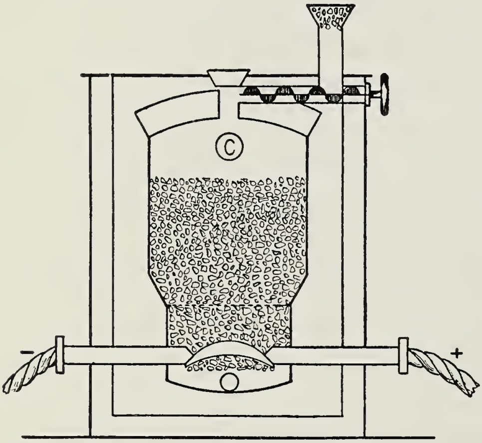


Figure 28.—The manufacture of phosphorus.

Preparation. Phosphorus is manufactured from bone ash or a pure mineral phosphate by removing the calcium and oxygen with which it is combined. This is accomplished by heating the phosphate with sand and carbon in an electric furnace. The sand, silica, combines with the lime forming a glassy *slag*, calcium silicate, which may be removed by a proper opening in the lower part of the apparatus. The carbon combines with the oxygen and passes off as a gas, carbon monoxide. The phosphorus vapor is passed out of an opening (c) in the upper part of the furnace and is condensed under water. This phosphorus is further purified by distillation. See Figure 28.

Physical Properties. Pure phosphorus is pale yellow in color, translucent and quite waxy in appearance. It melts at 44° and boils at 269°C. It is quite soft, can easily be cut with a knife and cast into any convenient form under slightly warm water. *It is always kept under water for storage or for handling, as it is very inflammable.* It is insoluble in water, but is very soluble in carbon disulphide and some other liquids. Its density is 1.8.

Chemical Properties. When exposed to the air, phosphorus slowly oxidizes and emits a faint glow or *phosphorescence.* The heat of the room may aid this oxidation and easily raise the temperature to the kindling point of the phosphorus, 35-45°C. The element burns in the air, giving off dense fumes of oxide of phosphorus. In oxygen it burns with dazzling brilliancy. It combines directly with many other elements besides oxygen, such as sulphur and the halogens. Phosphorus is exceedingly poisonous, less than $\frac{1}{6}$ of one gram being a fatal dose. Continued exposure to its vapor causes *necrosis*, a disease in which the jawbones and teeth are particularly liable to attack. Workers in match factories are especially subject to necrosis. A mixture of phosphorus and flour and water is often used as a poison for rats and other vermin. Phosphorus is a very dangerous chemical not only on account of its poisonous character, but also because it may cause painful burns which heal very slowly. *It must always be handled with forceps.*

Red Phosphorus. Yellow phosphorus under certain conditions may gradually change from the yellow material just described to a dark red powder. Simple standing of the yellow variety with exposure to light or heating to a temperature just below its boiling point will cause this change. The new substance differs remarkably from the other. Its density has increased to 2.1. It is not poisonous, neither is it soluble in carbon disulphide, nor does it take fire in the air below 240°C. If distilled and quickly condensed, the red form changes back to the yellow modification again. What term is applied to such physical modifications of a single element?

Compounds of Phosphorus. Phosphorus forms phosphine, PH_3, a hydrogen compound which is analogous to ammonia. There are two oxides of phosphorus, the trioxide and the pentoxide, sometimes called phosphoric anhydride. When phosphorus burns in an insufficient supply of oxygen or air, part of the product is the trioxide, P_2O_3. When there is an excess of air or the combustion takes place in oxygen, the pentoxide is formed, P_2O_5. The latter is the more common and important of the two. It is a snow white light powder that is characterized by its great attraction for water. Since it does not react with most gases, they can be thoroughly dried by passing them through a proper apparatus containing the pentoxide. These two oxides of phosphorus dissolve in water and give the acids of phosphorus. There are six acids formed in this way, depending upon the kind of oxide and the amount of water concerned in the reaction. Phosphorous acid (H_3PO_3) is not a common compound either as an acid or its salts. Phosphoric acid (H_3PO_4) is prepared by dissolving phosphorus pentoxide in water and by treating tri-calcium phosphate with concentrated sulphuric acid. It is the most important of the phosphorus acids. Many of its salts occur in nature. Pyrophosphoric and metaphosphoric acids are the names of the other acids. They are not of very great importance.

Uses of Phosphorus. The chief use of phosphorus in the elementary form is in the manufacture of matches. Matches may be divided into two classes, the common kind that ignite by simple friction, and the *safety* match that requires a prepared surface for this ignition. The common match is prepared as follows. The match stick is dipped for about ½ inch into some inflammable substance, as melted paraffin, and then into a paste of phosphorus, some *oxidizing* substance, as potassium chlorate, and a *binding* material, as glue. The friction of rubbing the match on any surface causes enough heat to ignite the phosphorus. The combustion is aided by the oxygen liberated from the oxidizing agent. The paraffin is then ignited and finally the wood. The process is really one of setting fire to a material of relatively high ignition temperature by using a series of substances of gradually increasing ignition temperature. A number of chemicals may be used as substitutes for those mentioned in the example cited above. Sulphur replaces the paraffin in the common sulphur match. Phosphorus sulphide may take the place of the phosphorus, manganese dioxide and red lead, of the potassium chlorate, and dextrin, of the glue.

The safety match cannot be readily ignited by friction, except on a prepared surface. The match tip itself contains an oxidizing substance, as potassium chlorate or potassium dichromate, an easily oxidized material, usually antimony sulphide or sulphur, some powdered glass to increase the friction, and some glue. The prepared surface is usually on the side of the match box and consists of a mixture of red phosphorus, a gritty material, as emery or fine sand, and glue. The friction of the match against the surface converts a little of the red phosphorus into vapor and ignites the match tip. The combustion is maintained by the reaction between the oxidizing and oxidized substances. In this way the wood is finally ignited.

The compound, acid calcium phosphate, $H_4Ca(PO_4)_2$ has two important uses, one of application in the household and the other of the greatest significance to agriculture. This compound is used in the preparation of the phosphate baking powders, being mixed in proper proportion with baking soda and starch. The phosphate is acid in reaction and together with the soda liberates carbon dioxide. The greatest use of acid calcium phosphate is, however, in the form of *acid phosphate fertilizers.* Other compounds of phosphorus are important for the same purpose. As already stated, phosphorus is a constituent of plants and is necessarily removed from the soil in this way. Since the supply of phosphorus in natural soils is limited and in certain cases very small, it can readily be understood that constant cropping of the land will diminish the amount of this material. In order to restore this fertility and maintain the cropping capacity of the soil, fertilizers must be added. Bone products, as bone meal, bone ash, etc., rock phosphate powder, and acid phosphate are used for this purpose. The acid phosphate is soluble in water, the others are not, but may become gradually soluble under soil conditions. The acid, therefore, has the great advantage that it is immediately available for plant use. The other forms become slowly available as the crops require them. It should be kept in mind, however, that acid calcium phosphate, also called super-phosphate, quickly reverts to insoluble phosphates on contact with the soil. Its great advantage comes from an effective fineness of distribution of available phosphorus compounds in the soil.

CARBON

Introduction. Carbon forms only about one five hundredth of the weight of the earth's crust. Yet its properties are such that it is one of the most important chemical elements. It is the characteristic substance of plant and animal products; thus it is essential to all life processes. In the mineral kingdom it is also very important. Limestone, for example, contains carbon. Coal, petroleum, and natural gas contain carbon. It is generally assumed that all such carbonaceous matters are derived from plant and animal origin. Carbon is remarkable for the very large number of compounds which it forms with other elements, especially oxygen and hydrogen. Compounds of carbon are more numerous than all other compounds put together.

Distribution. Carbon occurs in nature in both the elementary and compound forms. In the free state it occurs in the three allotropic forms, one amorphous, and two crystalline, namely the diamond and graphite. All these are very nearly pure carbon, but differ in their properties from one another. Amorphous carbon includes a number of varieties of carbon which differ merely in their degree of purity, fineness of division, and mode of preparation.

As a combined substance carbon exists in an enormous number of natural compounds. *In the air* carbon dioxide is always present and is the most common gaseous compound of the element. *In the earth* certain carbon compounds exist in the gaseous form. Natural gas is a mixture of chemical substances, part hydrogen and nitrogen, but principally compounds of hydrogen and carbon. The *fire damp* of mines, methane, is such a compound. Carbon dioxide also exists as a gas in the earth's crust. It is the deadly *choke damp* of mines and wells.

Water contains carbon dioxide in solution. The sparkling character and the effervescence of many natural spring or mineral waters is due to the presence of carbon dioxide. Moreover, the limestone and other mineral compounds held in solution in natural waters contain carbon. *Petroleum oils,* deposits of which exist in many parts of the world, rae largely composed of combined carbon.

Many solid minerals contain carbon. Examples of these are the different kinds of coal and the carbonates of metals which constitute great strata of rocks and are found in almost every locality. Calcium carbonate is especially important, as it is found in enormous deposits of limestone and marble. Other important carbonates are those of sodium, magnesium, iron, zinc, copper and lead.

All vegetable and animal substances are compounds of carbon. In fact they are generally mixtures of many different compounds. The number of carbon compounds constituting the great variety of living organisms is almost without limit. More than 100,000 compounds have been prepared artificially which contain this substance. The synthetic dyes are instances of this type of compound.

PREPARATION AND PHYSICAL PROPERTIES OF CARBON

The Diamond. Diamonds are found in considerable quantities in several localities, especially in South Africa, the East Indies and Brazil. When found they are usually covered with a rough coating which is removed in the process of cutting. Artificial diamonds may be prepared by dissolving carbon in molten iron and causing it to crystallize under great pressure and at a high temperature. This is done by plunging the molten iron into cold water. The outer layer hardens first, then the inner portions. The carbon is forced out of the solution under pressure and forms small crystals. The iron is dissolved by hydrochloric acid and the diamonds are left undissolved.

The diamond is a crystalline solid with a density of 3.5. It is the hardest substance known, a poor conductor of heat and electricity, but has a high refractive and dispersive influence upon light. It varies from colorless to black. The diamond is practically pure uncombined carbon, though it may contain some mineral matter. Few chemical agents have any action upon it; but, when heated in oxygen or the air, it blackens and burns, forming carbon dioxide. Black diamonds as well as broken and imperfect stones which are valueless as gems are used for glass cutting and for grinding hard substances.

Graphite. Graphite is found in large quantities in Ceylon, Siberia, and some parts of the United States and Canada. The purer grades are rare, however. Artificial graphite is produced in somewhat the same way as diamonds. The molten mass of iron and carbon is allowed to cool by itself. A portion of the carbon separates as graphite diffused throughout the iron. In large quantities for commercial purposes, graphite is manufactured by heating carbon in an electric furnace with 3 per cent of iron.

Graphite is a gray, lead-like solid, which is very shiny and greasy to the touch. It was formerly supposed to be a peculiar form of lead. Thus it has long been called *black lead* and *plumbago.* Its density is about 2.15. The properties of graphite vary, depending upon its source. It is more easily attacked by reagents than the diamond. It is used as a lubricant, as a protective covering for iron in the form of a polish or paint, and in the manufacture of lead pencils and crucibles for industrial purposes.

Coal. Coals of various kinds were probably formed from the accumulations of vegetable matters in former years. These became covered with earthy material and were thus protected from rapid decay. Under various natural agencies, such as heat and pressure, the organic matter was slowly changed into coal. In hard, or anthracite coal, these changes have gone the furthest and this variety is nearly pure carbon. Soft, or bituminous, coals contain considerable organic matter besides carbon and mineral substances.

Peat, lignite, soft coal and anthracite represent in a general way different stages in the decomposition of vegetable matter in the absence of air. Water and compounds of carbon and hydrogen are given off in the process. The following table shows the change in composition and the relations of the substances to fresh wood on the one hand and charcoal and coke on the other.

Table IV.— A Comparison of the Composition of Fuels.

	Percentage excluding ash and moisture		Percentage Ash	Percentage Moisture (air dry)	Calorific value per gm. in calories
	Carbon	Hydrogen			
Wood	45	6	1.5	18-20	2700
Peat	60	6	5-20	20-30	3500
Lignite	70	5	3-30	15	3000-6000
Soft	82	5	1-15	4	6600-8000
Anthracite	94	3	1.5	2	7000-8000
Charcoal	95	1.7	4	6.5	8080
Coke	96	0.7	3.4-11	2	7700

The gradual increase in the percentage of carbon and the decrease in the amount of hydrogen is apparent. There is also an increase in the calorific value of the fuels as the scale is descended.

Amorphous Carbon. There are many varieties of amorphous or non-crystalline carbon. Pure carbon is best prepared by charring sugar. The other elements of which sugar is composed, hydrogen and oxygen, are driven off in the form of water and pure carbon is left behind. It is a soft, black, lustrous powder.

The different forms of amorphous carbon may be prepared in more or less pure condition by heating certain carbon compounds without access of air. The conditions are such that but little oxidation can take place.

Lampblack is produced when tar, resin, petroleum, or other similar substances are burned with an insufficient supply of air or oxygen. A very smoky flame is produced. The smoke is composed of minute particles of lampblack which may be collected in proper receptacles. Soot is also a product of imperfect combustion of oil or coal. Both lampblack and soot usually contain oily impurities.

Charcoal is produced by heating wood or similar vegetable matter in pits or retorts in such a way that only a very limited combustion can follow. The older method was to arrange the wood in a pile, cover it with sods, make a few openings for inlet of air, set the pile on fire, finally close all openings and allow the whole to cool. At first the carbon and hydrogen of a part of the wood compounds burn. Later, however, other portions of the wood are simply heated, not burned. Their hydrogen and oxygen are liberated, but the carbon remains. In the newer process the wood is heated in retorts without access of air. The process is commonly called *destructive distillation.* The wood is decomposed, the hydrogen and oxygen and a small part of the carbon are expelled as gaseous compounds, and the latter may be condensed by passing them through cooled pipes. The charcoal remains in the retort. The older process was very wasteful since no effort was made to save the compounds liberated as gases. These are recovered, however, in the newer process, and include wood alcohol, acetone, and acetic acid, all valuable for certain commercial uses. Charcoal contains the mineral compounds present in the original wood.

Animal Charcoal is prepared by a process similar to that by which wood charcoal is produced. Waste animal matters like leather clippings are heated in closed retorts. Bone charcoal is a variety of animal charcoal. The carbon of the organic compounds closely associated with the bony tissue is distributed in a very porous condition throughout the bone charcoal.

Coke is produced by heating soft coal so that only a limited combustion may result. It is quite important that no more carbon be lost by the method than is absolutely necessary from the nature of the operation. The bee-hive oven is somewhat like the older method for the production of charcoal. It is a wasteful process since no effort is made to utilize the gases given off. The newer coke ovens are designed to produce coke, but at the same time to recover the gaseous and liquid materials given off by the treatment. The gases are used for illuminating purposes. The liquid *coal tar* is valuable. This is a complex mixture which may be refined by the same general method used in refining crude petroleum. Some hydrocarbons, as benzol and naphthalene, and carbolic acid and aniline may be secured from the tar. These serve as a starting point for the synthetic dyes, many drugs, and other chemicals. Ammonium compounds are also a by-product of the process and they are valuable for all the uses of ammonia, both household, industrial, and agricultural. Some of the coke is formed as a dense cake on the sides and roof of the retort. This is called retort or gas carbon and is quite pure carbon.

Lampblack, vegetable charcoal and animal charcoal are black and easily powdered. Coke has often a brilliant steel color. Gas carbon resembles coke, though it also resembles graphite in some respects. These are all, generally speaking, poor conductors of heat and electricity. All forms of carbon strongly resist attempts to melt or to vaporize it, though the electric arc probably does both.

All forms of carbon, except the diamond, exhibit a remarkable surface adhesion for matters in solution and for gases. For this reason considerable charcoal is used as a filtering medium. It often completely decolorizes colored liquids, it can withdraw certain compounds from their solution, and it can absorb large quantities of water vapor and other gases. Another characteristic property of all forms of carbon is their insolubility in liquid solvents. Practically the only liquid solvent for carbon is molten iron. All forms are odorless, tasteless solids, insoluble in water and characterized by their stability towards heat.

Chemical Properties. Carbon is one of the most remarkable of the elements in its chemical properties. There is at present a greater number of known compounds containing carbon than of any other element. The chemical changes taking place during the growth of plants and animals give rise to an enormous number of carbon compounds. It is possible by artificial processes in the laboratory or factory to produce a large number of carbon compounds which are different from those of natural origin. Though the chemist may make numerous substances which have not yet been found in any natural source, still there are a number of natural compounds elaborated by plant and animal life which man cannot synthesize.

Uncombined carbon is very inert chemically at ordinary temperatures; at high temperatures, however, it has a

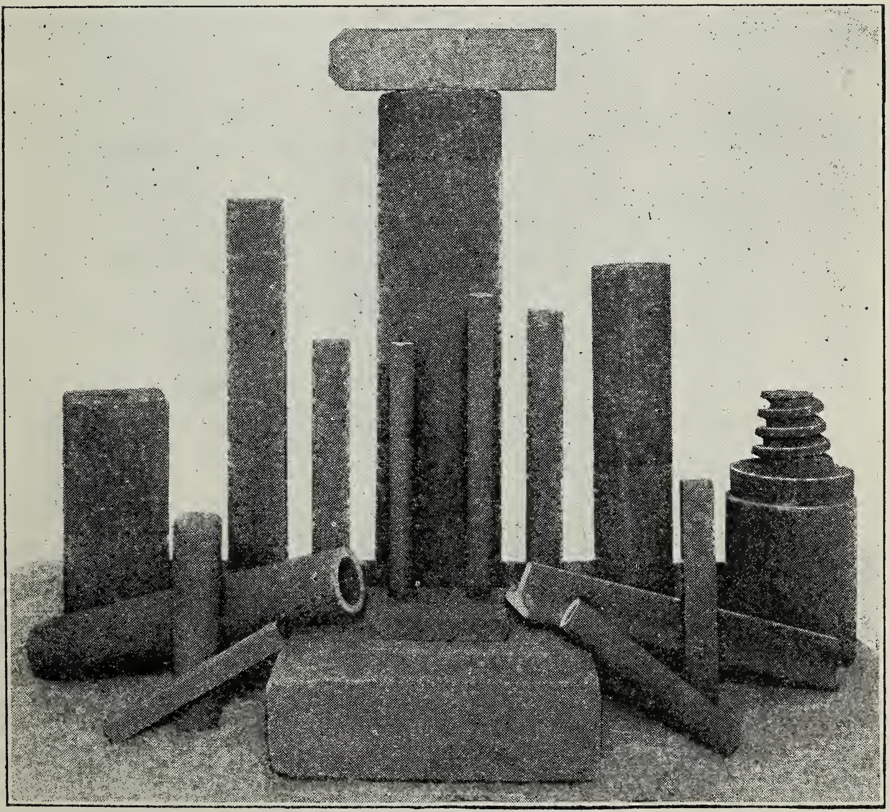


Figure 29.—Carbon prepared for industrial uses.

powerful attraction for certain elements, especially oxygen. The different forms of carbon are not affected by ordinary reagents, but at higher temperatures carbon combines with many elements forming carbides. Only two oxides of carbon are known, but there are more than a hundred compounds of carbon and hydrogen.

Uses of Carbon. The principal use of amorphous carbon is as fuel to furnish heat and power for all the demands of civilization. Enormous amounts of carbon in the form of charcoal and coke are used in extracting metals from their ores, especially iron. Retort carbon and coke are used for making electric light carbons and battery plates (Figure 29). Lampblack is used for printers' ink, indelible inks and black varnishes. Boneblack and charcoal are used for filtering agents, the former especially in sugar refineries.

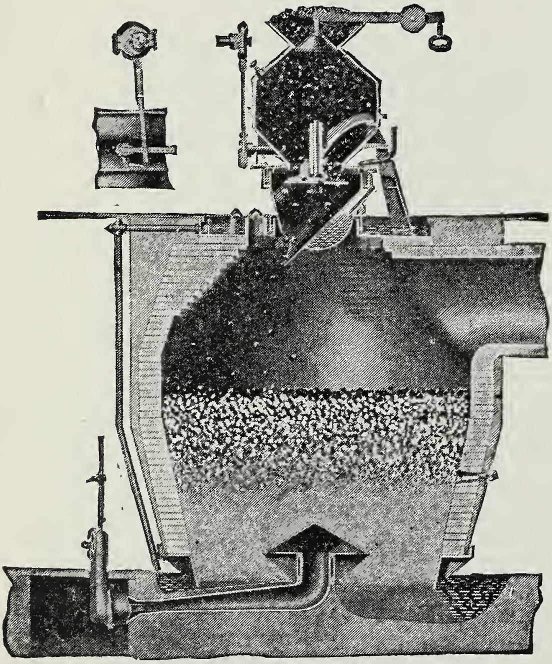


Figure 30.—A producer gas plant.

Compounds of Carbon with Oxygen. *Carbon monoxide,* CO. This compound is a light, colorless, almost odorless gas which is very difficult to liquefy. It is very poisonous, combining, when inhaled, with the red coloring matter of the blood and preventing the proper absorption of oxygen. It burns with a pale blue flame, forming the other oxide of carbon, carbon dioxide. Carbon monoxide is very active chemically, combining directly with many substances.

Carbon monoxide may be prepared in the laboratory by decomposing oxalic acid with strong sulphuric acid. It is prepared commercially on a large scale by passing steam over red-hot carbon. This process gives a mixture of hydrogen and carbon monoxide, the so-called water gas, which is extensively used for fuel purposes.

$$C + H_2O \rightarrow CO + H_2$$

Figure 30 shows a diagrammatic sketch of a producer gas plant, which also gives carbon monoxide mixed with nitrogen. Air is passed through heated carbon, and the final products are those stated. Steam may be used in manufacturing producer gas as well as water gas. In both cases the carbon is partially oxidized with steam. Carbon monoxide is the gas which burns with its characteristic flame on the surface of a coal fire, when the stove, having a good fire in the lower parts, has a relatively large supply of coal higher up. Figure 31. The carbon dioxide formed at first is reduced to carbon monoxide by coming in contact with the highly heated carbon.

$$CO_2 + C \rightarrow 2\,CO$$
$$2\,CO + O_2 \rightarrow 2\,CO_2$$

It combines with more oxygen on the surface and burns to form carbon dioxide. It is the presence of carbon monoxide in coal gas that is responsible for the death of many human beings, since it escapes into the house when there is insufficient draught in the stove.

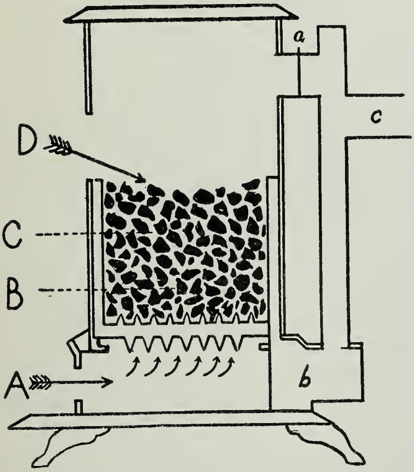


Figure 31.—The production of carbon monoxide in a coal fire.

Carbon dioxide, CO_2. This compound is produced in a variety of ways. (1) Whenever carbon burns or oxidizes with sufficient oxygen, carbon dioxide is formed. This is true of both free and combined carbon. The burning of fuels, the decay of plant and animal matter and the breathing of animals give rise to carbon dioxide. (2) When certain carbonates are heated, carbon dioxide is evolved. In the production of quick-lime much carbon dioxide is given off from the highly heated limestone. (3) The reaction between carbonates and acids gives carbon dioxide.

$$CaCO_3 + 2\,HCl \rightarrow CO_2 + CaCl_2 + H_2O$$

At ordinary temperatures carbon dioxide is a gas, which is colorless and practically odorless. By lowering the temperature either with or without a simultaneous increase of pressure, it may be reduced to a colorless liquid. When this is allowed to escape into the air, part of it instantly evaporates and absorbs so much heat that another portion is solidified to a snow-like material.

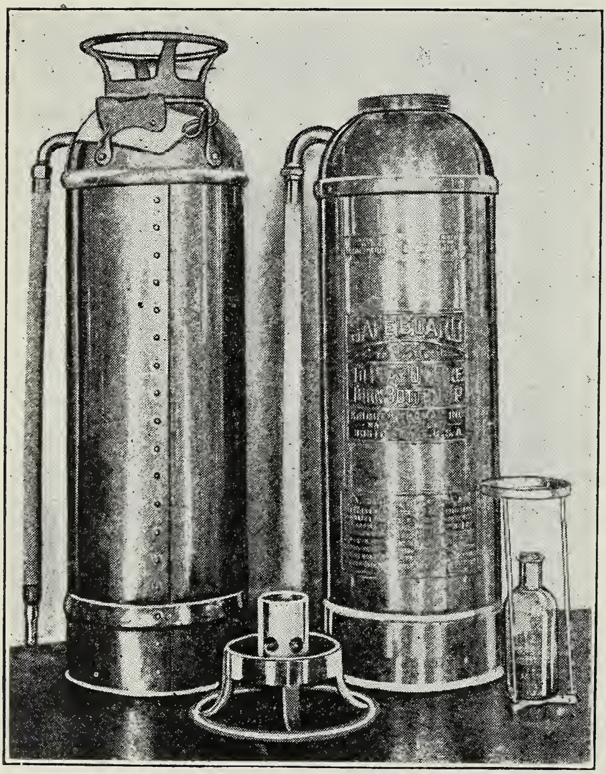


Figure 32.—An automatic fire extinguisher.

Carbon dioxide is about one and one half times as heavy as the air, one liter weighing 1.9641 grams. The gas is moderately soluble in water at ordinary temperature and pressure and imparts a somewhat biting, pungent taste to it. Such solutions are called carbonic acid though this compound is more or less of a hypothetical nature. It is very unstable and cannot be isolated. The relatively slight solubility of carbon dioxide in water proves that very little of the acid is formed. If, however, bases are present in the water, salts of carbonic acid are produced which are quite stable. The effect of carbon dioxide dissolved in rain water and soil water is very great upon the earth's surface. Limestone, especially, is very soluble in such water.

Carbon dioxide will not combine with more oxygen and, therefore, will not burn. Living animals plunged into an atmosphere of the gas die by suffocation or drowning. Instances of deaths from this gas, choke damp, in mines, wells and even silos are very common. It is always safer to lower a lighted candle in silos or wells before descending into them. If the candle burns, it is safe; if the candle goes out, it indicates that there is no oxygen there to support combustion or breathing. Burning substances are generally extinguished in carbon dioxide. Use is made of this fact in the preparation of automatic fire extinguishers. Figure 32. The main portion of the apparatus is a tank for a water solution of sodium bicarbonate. At the top is a support for a bottle of sulphuric acid. When the apparatus is needed, it is inverted and the acid and carbonate intermingle, producing carbon dioxide. The water carrying the gas is expelled under pressure and may be directed upon the fire. The carbon dioxide being heavier than air settles around the fire, crowding away the oxygen and extinguishing the flame.

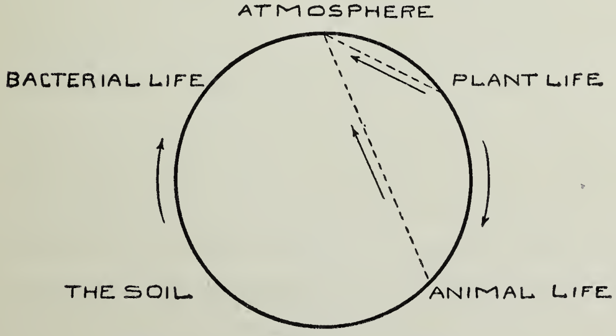


Figure 33.—The cycle of carbon.

Cycle of Carbon. The circulation of carbon is shown in the diagrammatic sketch, Figure 33. The carbon of plant and animal life comes from the atmosphere and may be returned to the atmosphere by them directly; or the element may be returned to the soil and then acted upon by bacterial life and again evolved into the air in the form of carbon dioxide. In other words, the atmosphere is the great storehouse of this element, which is so essential to the life of plants and animals.

SOME SIMPLE ORGANIC COMPOUNDS

Introduction. Chemistry may be divided into two great divisions, *organic* and *inorganic*. It was originally thought that those substances which constitute minerals and rocks were to be regarded as inorganic in character; that those substances which are produced by the life force of different organisms, whether plant or animal, were to be called organic. When, however, it was found that certain compounds characteristic of life processes can be prepared in the laboratory from inorganic materials, the line of division between these two classes could no longer be held. Almost all the compounds found in living organisms contain carbon. There are over 100,000 compounds, which do not occur in plants and animals, but have been prepared artificially, which contain carbon. The term *organic chemistry* at the present time includes both these artificial and natural substances. Organic chemistry has become the chemistry of the compounds of carbon. Inorganic chemistry treats of all other substances. Usually the simpler compounds of carbon, as the oxides and carbonates, are included in inorganic chemistry.

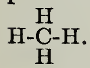
The carbon compounds excel in number those of all the other elements together, yet each compound is composed of relatively few elements. Many compounds contain only carbon and hydrogen and many more contain carbon, hydrogen and oxygen. A number of important organic substances contain carbon, hydrogen and nitrogen while others have oxygen in addition. Phosphorus, sulphur and the halogens are also present in many organic compounds.

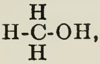
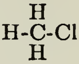
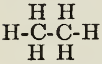
The great number of carbon compounds can be grouped into classes of similar compounds. It is possible to study the properties of each class as a whole. Knowing the general properties one may predict the characteristics of any member of that class. Some of the most important of these classes are hydrocarbons, alcohols, aldehydes, acids, ethereal salts, ethers, the organic bases and the carbohydrates.

The Hydrocarbons, compounds of carbon with hydrogen. Such compounds often occur in nature in natural gas and petroleum. Others are found in living plants and others are produced by the decay of organic matter in the absence of air. They may be made artificially by a variety of methods. The heating of organic matter without access of air is a general process, though there is a number of special methods for each particular compound.

Methane, or marsh gas, CH_4, is a very common example of a hydrocarbon. It is found in marshes, being formed by the decay of vegetable matter under water. It constitutes about 90% of natural gas and also collects in mines, coming from the pockets in coal beds. In the latter case its mixture with air is often called *fire damp* on account of its inflammable and explosive nature. It is one of the chief constituents of coal gas. Methane is a colorless and odorless gas and burns with a pale blue flame. Its density is 0.55, it is almost insoluble in water and is difficult to liquefy.

In methane each of the four valencies of carbon is satisfied with a hydrogen atom. The structure of this compound may be shown graphically somewhat as follows:



$\begin{array}{c}\text{H}\\ \text{H-C-H}\\ \text{H}\end{array}$. Other carbon compounds can be formed from this one by replacing any one or more of the hydrogens by other suitable elements or groups of elements. For example,  $H\text{-}\overset{H}{\underset{H}{C}}\text{-}OH$, in which one H has been replaced by an OH group. Other possible derivatives of CH_4 are  $H\text{-}\overset{H}{\underset{H}{C}}\text{-}Cl$  $H\text{-}\overset{H}{\underset{H}{C}}\text{-}\overset{H}{\underset{H}{C}}\text{-}H$, etc.

Acetylene, C_2H_2, is the gas commonly prepared by the action of water upon calcium carbide.

$$CaC_2 + 2\ H_2O \rightarrow C_2H_2 + Ca(OH)_2.$$

It is a colorless gas at ordinary temperatures and burns in the air with a smoky flame. It is used generally with a special burner which gives the right admixture of oxygen and produces an intensely luminous flame. Its use for lighting bicycle and automobile lamps and farm houses is very well known.

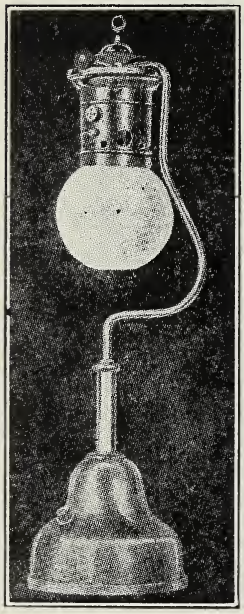


Figure 34.—A portable gasoline lamp.

Benzene, C_6H_6, is separated from coal tar. It is a colorless liquid which is very volatile. It is the starting point for the many coal tar or synthetic dye-stuffs.

Petroleum and its Products. The chief oil producing regions and the best known are those in Pennsylvania, Ohio, Kansas, California, and Texas in the United States, and those in Mexico and Russia. There are other valuable sources of petroleum, however, which are being investigated at the present time in Japan, India, and Asia Minor.

Petroleum is a thick oily liquid. It consists essentially of a mixture of hydrocarbons with larger or smaller amounts of nitrogen and sulphur compounds. It is principally liquid hydrocarbons in which are dissolved both gaseous and solid hydrocarbons. Some crude petroleum is used as a fuel and to enrich water gas, but most of it is refined. It is treated successively with sulphuric acid, caustic soda and water. It is then distilled and the distillates which pass over between certain degrees of temperature are collected by themselves. Some well known liquids collected in this way are gasoline, benzene, petroleum ether and kerosene or coal oil. These are all used as fuels and solvents. The higher boiling products are converted into mineral lubricating oils, vaseline and paraffin. None of these products is a definite chemical compound, but each consists of a mixture of hydrocarbons, the boiling points of which lie within certain limits. After the distillation process, coke remains in the retort. Over 200 commercial products are now made from petroleum. One of the principal applications of petroleum products has been that of using them for producing light, heat and power. Kerosene was formerly the material most commonly utilized for this purpose; but, within the last few years, gasoline has become of equal importance and those oils of higher boiling points are broken into gases which can be used in the same way. As an illustration of the utility of gasoline, Figures 34 and 35 show a portable lamp and its diagrammatic construction which is largely used for lighting both city and country dwellings. In this type of lamp the gasoline is pumped over by air

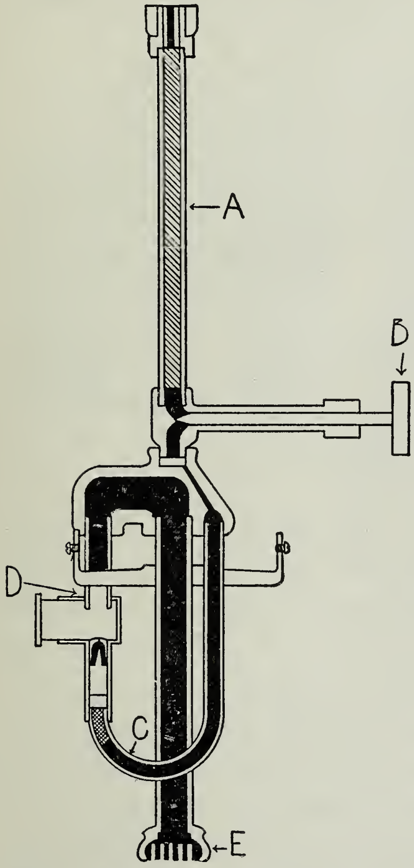


Figure 35. — Diagrammatic construction of a gasoline lamp.

pressure, vaporized, mixed with air and lighted at the outlet of the lamp. In the cross section of the lamp is shown (A) the asbestos filter tube through which the gasoline liquid passes, (B) the valve controlling the supply of liquid, (C) the tube that is heated to vaporize the gasoline, (D) the air inlet and mixing chamber, and (E) the burner. Figure 36 shows a cross section of a large plant for supplying gasoline gas for a dwelling or laboratory. The gasoline is vaporized by a current of air and piped to wherever it may be required.

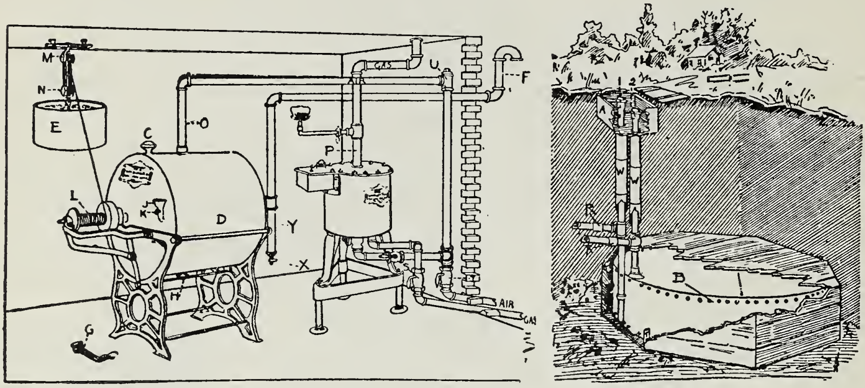


Figure 36.—A large gasoline gas plant.

In other cases the heavier petroleum oils are subjected to a heat treatment which gives a mixture of gases. These are liquefied under pressure in gas holders similar to those which are used for the transportation of oxygen and hydrogen. Upon releasing the pressure the liquid vaporizes and the gas produced may be burned. This is the character of the Pintsch and Blau gases which are used for lighting railroad coaches and country residences.

The Alcohols. The alcohols form a large and important class of organic substances. The most common are methyl, or wood alcohol, and ethyl, or grain alcohol.

Methyl Alcohol, CH_3OH, is obtained entirely from the dry distillation of wood. It is a colorless liquid, having a density of 0.79 and boiling at 66°C. It burns with a colorless, hot flame. As it is a good solvent for organic substances, it finds many uses, especially in the manufacture of varnishes, but is very poisonous.

Ethyl Alcohol, C_2H_5OH, is formed by the fermentation of sugar (glucose). Like methyl alcohol it is a colorless liquid and burns with a colorless hot flame which does not deposit carbon as oil flames do. It boils at 78°C. and has a density of 0.78. It has a number of important uses, such as a solvent for fats, the preparation of essences, extracts, perfumes and medicines, the preservation of anatomical specimens, and the manufacture of thermometers which are exposed to very low temperatures. Mercury freezes at −39.5°C., while ethyl alcohol does not solidify until it reaches −112.3°C.

Ethyl alcohol is used not only for the above mentioned purposes, but also for the manufacture of spirituous liquors. The starch of potatoes, grains, rice, etc., is changed by means of certain ferments called *diastatic enzymes*, into glucose and maltose. *Malt*, produced from germinating barley, is used to bring this reaction about. The glucose or maltose is fermented into alcohol by the addition of yeast. Carbon dioxide, glycerine, and other alcohols are also formed in the process. The ethyl alcohol is distilled from the mixture of other alcohols called fusel oil. The last traces of water are removed from the commercial alcohol by distilling it with lime.

In small quantities alcohol causes intoxication; in large quantities it acts as a poison. The intoxicating properties of such liquors as beer, wine, and whiskey are due to the alcohol present. Beer contains from 2 to 5% of alcohol, wine from 5 to 20%, and whiskey about 50%. The ordinary alcohol of the druggist contains about 94% alcohol and 6% water. 100% alcohol is called *absolute alcohol.*

The cost of manufacture of 94% alcohol is about 35 cents a gallon. There is a tax of $2.00 a gallon, however, imposed by the government, which makes it impossible from an economical point of view to use this in manufacturing processes. In 1906 Congress passed an act by which the tax is removed from alcohol, provided it is *denatured.* This means that the alcohol is mixed with some substance that prevents its use as a beverage, but will not interfere with its use for manufacturing processes. Wood alcohol and pyridine are some substances that are added to denature alcohol. The possible utilization of alcohol as fuel to take the place of kerosene and gasoline, when the natural supply of the latter is exhausted, adds another point of interest and extreme importance to this compound.

Glycerine, $C_3H_5(OH)_3$. This compound is an alcohol with three hydroxyl groups. It is a sweet, colorless, oily liquid, which is prepared from fats in the process of making soap. It is used in the manufacture of nitroglycerine and dynamite, soaps, pharmaceutical preparations, inks, as a food preservative and a lubricant.

Aldehydes. Formaldehyde is made by oxidizing methyl alcohol, drawing air through warm alcohol, and passing the warm mixture of vapors over heated copper. It is a colorless irritating gas and very soluble in water. The name *formalin* is applied to the 40% water solution of formaldehyde. This solution is used as a disinfectant and preservative and in agriculture for treating seed grains and potatoes to prevent fungous diseases from attacking them.

Organic Acids. These compounds are the direct products of the oxidation of aldehydes.

Acetic acid, CH_3COOH, is formed by the dry distillation of wood. The crude product is called *pyroligneous acid.* Pure acetic acid is called *glacial* acetic acid, since it solidifies at 17°C. and is thereby separated from any water which may be present. Vinegar is dilute, impure acetic acid which is formed by the fermentation of alcohol. This is effected by the agency of a small organism commonly called mother of vinegar. The various kinds of vinegar, are made by this process. In the manufacture of cider vinegar, the sugar present in the cider first undergoes alcoholic fermentation. The alcohol then undergoes acetic fermentation. The amount of acetic acid in vinegars varies from three to six per cent. Acetic acid is a colorless liquid and has a strong pungent odor.

Butyric acid is present in butter and is set free when the butter becomes rancid. The ordinary flavor of butter is partly due to the presence of derivatives from butyric acid.

Oxalic acid is found in certain plants, especially the sorrels.

Lactic acid is produced by the fermentation of milk sugar and is, therefore, found in sour milk. It is present also in pickles, in silage and in the gastric juice.

Tartaric acid occurs either in the free form or as salts in many fruits. Potassium acid tartrate, *cream of tartar*, is obtained from the walls of wine casks as a dark solid called tartar or argol. The so-called cream of tartar baking powders consist of a mixture of cream of tartar, baking soda, and starch. When water is added to this mixture, the cream of tartar reacts with the soda, liberating carbon dioxide, which escapes through the dough and makes it light and porous.

Malic acid occurs in fruits. Citric acid occurs in lemons, oranges and other acid fruits.

Esters are salts of alcohols and acids. There are many of them present in fruits and flowers, causing their characteristic odor and taste. Some of these compounds which are the natural flavors of drinks, extracts and perfumes can be prepared artificially and are often used instead of the natural flavors.

Fats and oils. The most important esters are the natural fats and oils which consist essentially of compounds of glycerine with stearic, oleic and palmitic acids. These esters are called *stearin, olein, and palmitin.* Olein is a liquid fat; the other two are solids. The relative amount of olein consequently determines the fluidity of fats. Tallow and beef suet are largely stearin. Palm oil is largely palmitin. Lard and olive oil contain much olein. Butter is a mixture of several fats.

Soap is prepared by treating fats with alkalies until the fats have been broken down into glycerine and alkali salts of the acids mentioned above. The process is generally referred to as *saponification.* The soap is soluble, but may be precipitated out of the mixture by adding much salt, literally salting it out. The glycerine may be separated by mechanically working it out. The soap is washed to free it from alkali, perfumed, colored and perhaps filled with borax or other material, depending upon its use and character. Hard soaps consist of the sodium salts, and soft soaps of the potassium salts of the fatty acids. Palm oil, cocoanut oil, butter and lard produce white soaps. Castile soap is made from olive oil. The cheaper soaps or the yellow varieties are made by mixing fats with rosin, cottonseed oil, bone grease, etc. When soaps are used with water containing calcium or magnesium salts in solution, these metals combine with the acids of the soap and form insoluble compounds which are precipitated. In this way much soap is consumed before it gives rise to its characteristic lather or suds.

Ethers. Ordinary ether, ethyl ether or sulphuric ether, $(C_2H_5)_2O$, is a colorless, volatile liquid with a sweet odor. It boils at a very low temperature, 35°C., and is very inflammable. It is used as a solvent for fats and other compounds and as an anaesthetic in surgery. Ether is prepared from ethyl alcohol by the action of sulphuric acid.

Carbohydrates are compounds of carbon with hydrogen and oxygen, the latter two being in the same proportion in which they occur in water. The most important substances of this class of compounds are sugars, starches and cellulose. *Cane sugar*, or sucrose, $C_{12}H_{22}O_{11}$, is the most common sugar. *Maltose*, malt sugar, and *lactose*, milk sugar, have the same percentage composition of hydrogen, oxygen and carbon as sucrose, but the arrangement of these elements is different. These three sugars, therefore, have slightly different properties. Cane sugar melts at 160°C. and at 200° it forms a brown substance called caramel which is used for coloring foods and beverages. Milk sugar is not as sweet as cane sugar. In fact, its sweetness is hardly perceptible. It is used in prepared foods and homeopathic pellets.

Cane sugar is prepared from either the sugar cane or the sugar beet. The plant material is crushed or pulped and the juice extracted. The juice is clarified by means of lime, then evaporated in vacuum pans to prevent the charring and decomposition of the sugar. The sugar crystals are separated from the molasses by centrifuging. Raw or brown sugar is thus obtained. This is refined by dissolving in water and filtering through animal charcoal. The juice may again be concentrated and then crystallized. Maple sugar is made by evaporating the sap obtained from the hard maple tree. Its sweetness is due to the presence of cane sugar, though other products present in the maple syrup impart its characteristic flavor.

Glucose, or dextrose, or grape sugar, $C_6H_{12}O_6$, is a white crystalline solid which is less sweet than cane sugar. It melts at 150°C. It is found in many fruits, especially grapes, from which it obtains its name. It also occurs in the seeds, the roots, leaves and blossoms of plants. It is formed by the breaking down of sucrose and starch by enzyme action. Glucose may be produced artifically by treating starch with acids. Since it is cheaper than cane sugar, it is manufactured extensively and is used in making jellies, candy and syrups. Glucose is commonly called corn syrup.

Fructose, or levulose, or fruit sugar, $C_6H_{12}O_6$, has the same percentage composition as glucose, but the atoms composing the molecule are differently arranged. It occurs in fruits and honey.

Starch $(C_6H_{10}O_5)_x$ is found in grains, potatoes and fruits. It can be mechanically separated by means of water from its mixture with other compounds in corn and potatoes. In the United States it is obtained chiefly from corn, nearly 80% of which is starch. In Europe it is secured principally from the potato. Starch consists of small grains. The appearance varies depending upon the source of the starch. Chemically, however, all kinds of starch are the same. Hot water causes the grains to swell and burst. The starch paste thus formed, when suspended in water, gives starch solution, though the starch does not form a true solution. Starch is used in foods, in making cloth, paper and glucose, and for starching clothes.

Dextrin is formed from starch by the action of heat or dilute acids. Impure dextrin is a sticky substance used for mucilage.

Cellulose, $(C_6H_{10}O_5)_x$, is the frame work of the plant, as it forms the walls of the plant cells. Cotton, linen, and paper are almost entirely cellulose. The finer grades of paper are made from linen and cotton rags, the cheaper grades from straw and wood. Swedish filter paper is a purified form of cellulose. Cellulose is an amorphous white substance insoluble in most solvents. When treated with concentrated sulphuric acid it is decomposed into glucose. Nitric acid gives nitro-cellulose, sometimes called pyroxylin, or *gun cotton,* used as an explosive. When exploded it yields only colorless gases; hence it is used especially in the manufacture of smokeless gunpowder. Collodion is nitro-cellulose dissolved in alcohol and ether. When the solvent evaporates it leaves a thin film of tough transparent material. This can be used to make photographic films and to protect wounds. Celluloid is a mixture of gun cotton and camphor.

Alkaloids are nitrogenous substances occuring in many plants and trees and often used in medicine on account of their physiological effect. Chemically they resemble ammonia, their aqueous solutions are alkaline and they unite with acids to form salts. Quinine is found in the bark of the cinchona tree. It is used as a medicine in the treatment of fevers. Morphine is found in the sap of unripe poppies. When this sap is partially dried it is called opium. Cocaine is a crystalline solid present in cocoa leaves and used as a local anaesthetic. Theine, or caffeine, occurs in tea and coffee. Nicotine is a very poisonous liquid which occurs in the leaves of the tobacco plant.

SILICON

Introduction. Silicon always occurs in nature in the combined state. In fact it is very difficult to prepare the substance in the free form. In respect to chemical relations there is a close resemblance between carbon and silicon. Silicon is the characteristic element of the inorganic or mineral kingdom in a similar way that carbon is the characteristic element of the plant and animal kingdom.

Distribution. Silicon is the most abundant element next to oxygen and constitutes more than ¼ of the earth's crust. It does not occur free in nature, but its compounds are very abundant and very important. Its principal compound is silica or silicon dioxide, SiO_2. Other important compounds are silicates, or salts of silicic acid. Silica and silicates form a large fraction of the earth's crust. Silicon is found in the ash of most plants and in very small quantities in animal organisms. It is not, however, regarded as essential for either plant or animal life. Its presence in living tissue is probably due to its great abundance in the soil.

Kieselguhr, diatomaceous earth, is an interesting substance containing about 90% pure silica when dry. This material is formed by the action of diatoms in bodies of water. The silica shell of these plants is secreted by them and, when the organism dies, is deposited in large quantities. The deposits of kieselguhr in California are the largest and purest of any that are known.

Preparation. Silicon is most easily prepared by heating powdered quartz, silica, with magnesium powder. The magnesium reduces the silica by removing the oxygen. An impure form of silicon may be obtained by reduction of quartz with carbon in an electric furnace.

Properties. The element silicon resembles carbon in many respects. It has several allotropic forms, corresponding to those of carbon. The crystalline form is very hard and is inactive towards chemical reagents. The amorphous variety has, in general, properties more similar to charcoal. Silicon melts only at the highest temperature. It is not affected by oxygen at ordinary temperatures, but when strongly heated burns with great brilliancy. It is not attacked by acids under ordinary conditions.

Compounds of Silicon. Silicon forms a number of compounds of the same general type that carbon forms. These compounds, though, are quite different in their properties from the corresponding carbon compounds.

Silicides. Silicon combines with some other elements to form binary compounds called silicides. They are very stable at high temperatures and are usually made by heating the proper ingredients in an electric furnace. Carborundum is the most familiar and probably the most important sub-

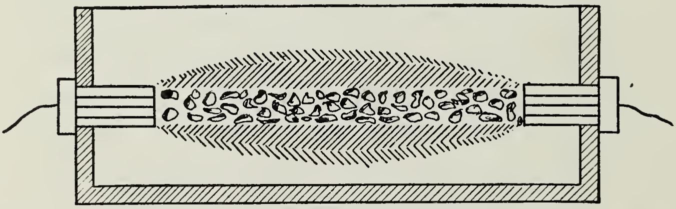


Figure 37.—Cross-section of an electric furnace.

stance of this character. It is a silicide of carbon, and is made by heating coke and sand in an electric furnace at 3,500°C. Figure 37 is a cross-section view of the type of electric furnace in which carborundum is prepared. The charge of sand and coke is placed in the proper position and surrounded by the walls of the furnace. A powerful electric current is passed through the mass from one pole to the other. After cooling, the furnace may be taken apart and the products removed. Carborundum consists of beautiful purplish black crystals which are very hard. It is used as an abrasive. Ferrosilicon is a silicide of iron which is present in certain kinds of steel.

Silicon Dioxide. This substance occurs in a great variety of forms in nature, both in the amorphous and the crystalline condition. Quartz is a variety of silica. When pure it is perfectly transparent and colorless. Some colored varieties of quartz are the amethyst, rose quartz, and smoky or milky quartz. Other varieties of this substance are onyx, jasper, opal, agate and flint. The colored varieties are caused by the presence of certain impurities, usually mineral in character, but organic in the case of smoky quartz. The greater proportion of sand and sandstone is silicon dioxide. Silica is also found in the hard parts of straw, of some species of the horse-tail (equisetum) and the bamboo.

Artificial silica is an amorphous white powder. The crystallized form is very hard and has a density of 2.6. It is insoluble in water and in most chemical reagents and requires the hottest oxyhydrogen flame for fusion. With the exception of hydrofluoric acid, acids have very little effect upon it, but it is soluble in alkalies, forming silicates. In the form of whetstones silica is used for grinding. The clear crystals are used to make spectacles and optical instruments. Pure sand is used in glass manufacture.

Some of the uses of kieselguhr are as a filtering and absorbing medium and a material for insulating, for deadening sound and for fire-proofing. Fused silica or quartz is used for the manufacture of laboratory and industrial apparatus where resistance to acids and a small coefficient of expansion are desired. Figure 38 shows a group of laboratory utensils made from *vitreosil*, pure fused silica.

Figure 38.—Laboratory apparatus made of silica.

Silicic Acids. Silicon forms two simple acids, *ortho and meta.* Orthosilicic acid minus water gives metasilicic acid.

$$H_4SiO_4 - H_2O \rightarrow H_2SiO_3$$

The difference between these is that the ortho contains a molecule of water more than the meta. Both forms, when heated, give silica and water. There are many complex acids of silicon, which, although they cannot be prepared in the pure state, occur in nature as salts in the form of rocks. These so-called *polysilicic acids* may be regarded as being formed when several molecules of orthosilicic acid combine with loss of water.

Mica is the potassium and aluminium salt of orthosilicic acid. It is found in nature in the form of large sheets and is used for making lamp chimneys, and as an insulator for electrical apparatus. Feldspar is a mixed potassium and aluminium salt of a polysilicic acid. Kaolin is the aluminium salt of a polysilicic hydrated acid. Some of the minerals frequently occur mixed together as regular components of certain igneous rocks. Granite is a more or less coarse mixture of quartz, mica and feldspar. Sandstone is composed of sand cemented together by clay or lime and colored brown or yellow by ferric oxide. The illustration of spheroidal granite (Figure 39) shows the manner in which the different minerals which constitute the granite are intimately associated. The light colored, glassy masses in the rock are quartz, and they, with the feldspar, give granite its characteristic hard resistant qualities.

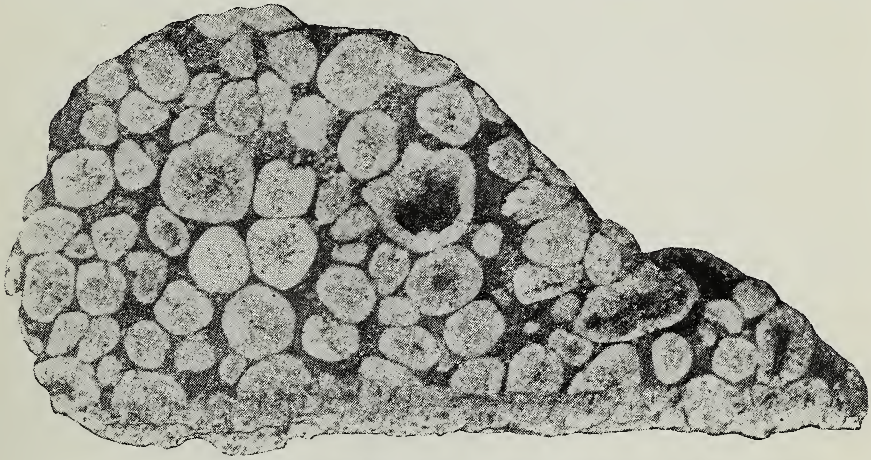


Figure 39.—A section of spheroidal granite.

SUMMARY

Chlorine is a very active element and always occurs in nature in the combined form. Chlorides are common and of great importance, notably common salt. Chlorine is prepared by oxidizing hydrochloric acid and by the electrolysis of chlorides. A characteristic property of chlorine is its attraction for hydrogen, forming hydrochloric acid.

This is an important compound of chlorine and has all the typical properties of an acid. The principal commercial use of chlorine, namely as a disinfecting and bleaching agent, is due to this attraction for hydrogen, as nascent oxygen is liberated from water by the process.

Sulphur occurs in both the free and combined forms. It is not only an important constituent of plant and animal life, but many of its compounds are valuable for commercial purposes. It has several allotropic forms which differ in their physical properties from one another, but have the same chemical properties. Sulphur is an active element chemically, hydrogen sulphide, carbon disulphide, and the sulphides and sulphates of the metals being examples of its compounds. But the most important compounds of sulphur are the oxides, sulphur dioxide and trioxide, and sulphuric acid. These substances are readily converted into one another by oxidation and reduction processes. Sulphuric acid, especially, is valuable since it is the foundation of many chemical industries.

Phosphorus always occurs in the combined form, since it is a very active element. There are two allotropic states of phosphorus, the yellow and the red. These differ in their physical properties quite markedly, but have the same chemical characteristics. The principal uses of phosphorus and its compounds are in the manufacture of matches, phosphate baking powders and fertilizers.

Carbon is an element of special importance to life. It is widely distributed in many thousand compounds. As an element and in its various compounds it is of the greatest value to mankind, serving for fuels, food, clothing, building materials, industrial articles and pharmaceutical preparations, etc. In other words, carbon enters into every phase of life and civilization. There are more carbon compounds than of all the other elements put together. Some of the principal classes of these are oxides, carbonates, hydrocarbons, alcohols, acids, esters, ethers, organic bases and the carbohydrates.

Silicon is the characteristic element of most rocks and minerals. It never occurs free in nature, but may be prepared in the elementary form by chemical means. It has several allotropic forms and is very inert. Some of its principal compounds are silica, silicides and silicates. These are also quite resistant to chemical change and are of chief interest in connection with the study of the earth's crust. Silica and the silicides have commercial uses.

These elements, together with oxygen, hydrogen and nitrogen, are the most important non-metals as far as their everyday relations are concerned.

QUESTIONS

1. State how chlorine, sulphur, phosphorus and silicon occur in nature.

2. Name some tests by which it is possible to distinguish between chlorine and hydrochloric acid.

3. Explain how chlorine bleaches.

4. Compare properties of hydrochloric acid and sulphuric acid.

5. Discuss the relative commercial importance of hydrochloric acid and sulphuric acid.

6. If hydrogen sulphide were a liquid, would it be necessary to modify the method of preparation?

7. What are the chief differences between the properties of the yellow and the red phosphorus?

8. Discuss the function of phosphorus in plants and animals.

9. Discuss the relation of carbon dioxide to plant and animal life.

10. In what way do the following substances differ from one another: peat, lignite and anthracite?

11. How could you judge the relative purity of different forms of carbon?

12. How can you tell the difference between soft and hard coal; between bone black and lamp black?

13. What are some of the differences in the properties of carbon monoxide and carbon dioxide?

14. When sugar is heated sufficiently to char it, what substances are formed and what elements are indicated?

15. Name the elements so far studied having allotropic forms.

16. What substances studied are used as bleaching agents? To what is the bleaching action due in each case?

17. For each of the following gases name a property which will distinguish it from the other gases given: hydrogen, oxygen, chlorine, nitrogen, carbon dioxide, ammonia.

18. Suppose four jars of gas were given to you, one containing carbon dioxide, another nitrogen, the third hydrogen and the last chlorine. By what tests could you identify the contents of each jar?

19. Write the equation illustrating the neutralization of hydrochloric acid by potassium hydroxide; of hydrochloric acid by calcium hydroxide.

20. State what gases you have studied can be identified without the use of chemical tests and how.

21. Make a table of any six gases studied showing five or more of the physical and chemical properties by which these substances may be identified.

22. What commercial uses are made of ammonia; of the different forms of carbon?

23. What is meant by the terms inert substance, destructive distillation, catalytic agent?

24. Name the following substances from their description: (a) A gas, heavier than air, has color, odor, and taste, does not burn but is very active, combining with other substances by simple contact with them. (b) A liquid, has sharp odor and taste, turns litmus red, attacks metals and minerals, and gives off a greenish yellow gas when treated with manganese dioxide.

CHAPTER V

A FEW IMPORTANT METALS

The metals are a class of elements which have certain properties in common. They are sometimes called the *base-forming elements*, since their hydroxides are bases. The distinction between a metal and a non-metal is not very sharp, since the hydroxides of a number of elements may act as both bases and acids.

Occurrence. A few metals, such as gold, platinum, and copper, occur in the free form in nature. They are usually found as compounds, of which the oxides, silicates, carbonates, sulphides, and sulphates are the most abundant forms. The term *mineral* is generally applied to all inorganic substances occurring in nature. An *ore* is a mineral substance from which a useful substance, as iron, can be extracted.

Extraction of Metals. The process of extracting a metal from its ores is called the *metallurgy* of the metal. While each metal has special processes of its own, there are several methods of general application which are employed.

(1) *Reduction of an oxide with carbon.* When oxides of metals are heated with carbon, the latter combines with the oxygen forming carbon monoxide and carbon dioxide which pass off as gases and leave the metal free. The principle of this extraction has already been demonstrated in the experiment upon copper oxide and carbon. The importance of this method is shown by its application to the reduction of iron from its oxides. If the ore is not already in the form of an oxide, it can be *roasted* or heated in a current of air. In this way, sulphides are changed to oxides and the sulphur is driven off as sulphur dioxide.

Simple direct heating is sufficient in some cases to change carbonates and hydroxides into the oxides.

(2) *Reduction of an oxide with aluminium.* It is impossible to reduce oxides of all the metals with carbon. In such cases aluminium may be used. The aluminium has a strong attraction for oxygen and abstracts it from the metallic oxide. This is sometimes called the Goldschmidt method, after its inventor. A practical application will be seen under the case of thermite.

(3) *Electrolysis.* The use of the electric current has made possible both experimental and commercial preparation of the metals which could not formerly be easily separated. The metal is prepared from its compound either by passing the electric current through a solution of a suitable salt of the metal or through a fused salt of the metal. The latter is usually deposited upon the cathode.

When a current of electricity is passed through conducting solutions, the latter are called *electrolytes.* The substance in solution which is electrolyzed is supposed to be broken up into two parts, or *ions*, the cation carrying a positive charge of electricity and going to the negative pole, and the anion carrying a negative charge and going to the positive pole. The poles are called *cathode* and *anode* respectively. An ion is an atom of an element plus an electrical charge. Or, an ion may be a radicle, or group of atoms, plus an electrical charge.

THE ALKALI METALS

Introduction. The name *alkali metals* is applied to a group or family of elements, because the hydroxides of sodium and potassium, which belong to the group, have long been called *alkalies.* These metals do not occur free in nature, but their compounds are widely distributed. Sodium and potassium, especially, occur in abundance in natural waters, in salt beds and in rocks. The metals are conveniently prepared by electrolytic methods.

The alkali metals almost always act as univalent elements in the formation of compounds. With the exception of lithium they form very few insoluble compounds. The compounds of sodium and potassium are so similar in their properties that they can be used interchangeably for most purposes. Sodium compounds are cheaper, however, and therefore, are used if possible. Sometimes certain properties of a sodium compound are such that the substance cannot be used for a specific purpose. Then the corresponding potassium compound is used.

SODIUM

Distribution. Large deposits of sodium chloride, common salt, have been found in various portions of the world. Natural waters, especially the ocean, and many lakes and springs contain large amounts of it. Sodium is also a constituent of many rocks and consequently is present in the soil formed from these. Though it does not seem to be necessary for plant life, it is present in plants, especially seaweeds and other marine plants. Besides common salt deposits, sodium is found in the form of nitrate, carbonate, borate and the double fluoride of aluminium and sodium.

Preparation. Sodium may be prepared by reducing the carbonate with carbon. The best method at present is to decompose fused sodium hydroxide or sodium chloride by means of the electric current. The process is carried on extensively at Niagara Falls.

Physical Properties. Sodium is a silver white metal about as heavy as water. It is so soft that it can be easily compressed into any shape desired.

Chemical Properties. This element is very active chemically, combining with most of the non-metallic elements such as oxygen and chlorine with great energy. This activity is shown by the rapid tarnishing of the metal when exposed to the air on account of the formation of the sodium oxide. In order to preserve the substance in the metallic form, the sodium is kept in kerosene which contains no water or oxygen. Sodium not only has a strong attraction for free oxygen and chlorine but it also is able to abstract these elements from their compounds. Such a reaction has already been demonstrated in the preparation of hydrogen by bringing sodium in contact with water.

Compounds of Sodium. *Sodium hydroxide,* caustic soda, lye, NaOH. This important substance may be prepared in a number of ways. It will be recalled that, in the preparation of hydrogen by the action of sodium upon water, the character of the liquid remaining was quite different after the reaction than before. It was soapy to the touch, bitter to the taste, and alkaline to litmus. The liquid was dilute sodium hydroxide, and this method is the simplest for preparing the compound. Commercially, the electrolytic methods are the most important at the present time. In the Castner process a solution of common salt is electrolyzed, in the Acker process fused sodium chloride is exposed to the action of the electric current. In both cases chlorine is evolved and is drawn away through pipes to the bleaching powder chambers. The sodium which is produced at the other pole is alloyed with mercury or lead and by ingenious devices is brought in contact with water in another chamber than the electrolytic cell.

In the Castner-Kellner apparatus, Figure 40, which serves for the manufacture of either sodium or potassium hydroxides, the two end compartments are filled with a brine of sodium or potassium chlorides and contain graphite electrodes, the positive poles. The central compartment contains the caustic alkali and an iron electrode, the negative pole. The positive current enters by the anodes and the chlorine is attracted and liberated there. The sodium or potassium is discharged upon a layer of mercury which covers the whole floor of the box and forms an amalgam.

The layer of mercury extends beneath the partitions and a slight rocking motion given to the cell by the cam (C) causes the amalgam to flow beneath the partition into the central compartment. Here the sodium is attracted to the cathode and when liberated there unites with the water, forming sodium hydroxide and hydrogen. The sodium hydroxide in the solution can be run off and evaporated to the solid material. Some of the compound is still manufactured by the older process of treating sodium carbonate with water slakedlime.

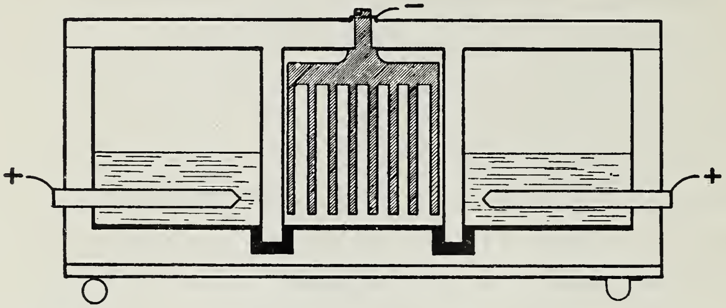


Figure 40.—Apparatus for the manufacture of caustic alkalies.

Sodium hydroxide is a white, crystalline, brittle substance which absorbs water and carbon dioxide rapidly from the air. It is a very corrosive, or caustic, substance and has a disintegrating action upon most animal and vegetable tissues. It is a strong base or alkali and is used in the household under the name of lye for cleansing purposes. It has numerous industrial uses an example of which is its application to soap making.

Sodium chloride, common salt, NaCl. This compound is very widely distributed in nature. It constitutes about 3½% of the water of the ocean. In other words, about 90% of the soluble salts in the salt water is sodium chloride. Thick layers of the salt, possibly deposited at one time by the evaporation of salt water, are found in many places. New York, Michigan, Ohio, and Kansas have important salt deposits. The substance is mined, especially if in the form of rock salt, or a strong brine is pumped from deep wells sunk into the deposits and is then evaporated until the salt crystallizes out. In warm climates salt water of the sea is allowed to overflow tracts of land, then retained there by dikes and evaporated by the heat of the sun.

Enormous quantities of salt are produced each year for commercial purposes. As it is the most abundant compound of both sodium and chlorine, it serves as the starting point for nearly all compounds containing those elements. Many substances of the greatest importance to mankind are in this list. Soap, glass, hydrochloric acid, soda and bleaching powder are a few examples. Small quantities of salt are essential to human and animal life. Pure salt does not absorb water. Ordinary table salt contains impurities such as chlorides of calcium and magnesium. The presence of these compounds is responsible for the fact that table salt becomes moist when exposed to the air.

Sodium sulphate, Glauber's salt, Na_2SO_4, is extensively used in the manufacture of sodium carbonate and glass. Small quantities are used in medicine.

Sodium thiosulphate, hyposulphite, hypo, $Na_2S_2O_3$. This substance is used in photography to fix the negative after development. It dissolves the undecomposed silver bromide and clears the plate. It is also used in the bleaching industry to absorb the excess of chlorine left upon the fabrics and thus prevent injury to them.

Sodium carbonate, sal soda, washing soda, Na_2CO_3. This important compound may be prepared by two different methods. The so-called Leblanc process is the older and the less satisfactory one. It involves considerable expense for fuel, there is a loss of much matter, and the by-products, with the exception of hydrochloric acid, are not valuable. The production of this hydrochloric acid is the only salvation of the method and is responsible for its successful competition with the other process, the Solvay method. The Leblanc process involves several distinct reactions. Common salt is treated with sulphuric acid and converted to the sulphate. This is next reduced to sodium sulphide by carbon. The sulphide is finally changed to carbonate by heating with calcium carbonate. The process is carried on upon the hearth of a reverberatory furnace, where the heated gases from the fire are deflected from the roof upon the materials. Figure 41 shows the cross-section of such a furnace. The equations for the reactions are shown below.

$$\begin{aligned}&NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl\\&NaCl + NaHSO_4 \rightarrow Na_2SO_4 + HCl\\&Na_2SO_4 + 2\ C \rightarrow Na_2S + 2\ CO_2\\&Na_2S + CaCO_3 \rightarrow Na_2CO_3 + CaS\end{aligned}$$

The Solvay process is the more modern and the more economical. The principle of this process is to pass ammonia gas and carbon dioxide gas into a strong solution of common salt. Sodium bicarbonate, $NaHCO_3$, is formed in this way and, being sparingly soluble under the conditions, is precipitated. It may be changed into sodium carbonate by heating. In the Solvay method there is only one waste by-product, calcium chloride. The ammonia gas is used in a constant round with only a slight loss. Calcium carbonate furnishes the carbon dioxide and the quicklime required in the process. The Solvay process is an excellent illustration of a chemical manufacturing process where there is little loss of material in the reacting chemicals. The equations representing the ammonia-soda process are as follows:

$$\begin{gathered}NaCl + NH_4HCO_3 \rightarrow NaHCO_3 + NH_4Cl\\2\ NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2\end{gathered}$$

Sodium carbonate forms large crystals with ten molecules of water of crystallization. It is mildly alkaline and is used for laundry purposes under the name of washing soda. Commercially it is used in the manufacture of glass, soap, and many chemical reagents. Agriculturally it is of interest, since it is one of the substances which is responsible for the so-called black alkali effect in soils.

Sodium bicarbonate, baking soda, saleratus, $NaHCO_3$. This compound is prepared directly in the Solvay process. Its properties are similar to those of the sodium carbonate. The principal use of the bicarbonate is in the preparation of baking powders. As it is a mild alkali and contains carbon dioxide, when brought in contact with an acid reacting substance in the presence of water, there is a reaction and carbon dioxide is liberated. This gas forces its way through the dough and makes it porous and light.

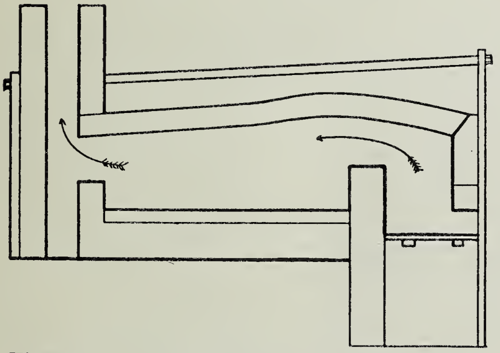


Figure 41.—Cross-section of a reverberatory furnace.

Sodium nitrate, Chile saltpetre, $NaNO_3$. Sodium nitrate is found in nature in arid regions, probably formed by the decay of organic substances containing nitrogen, in the presence of air and sodium salts. The largest deposits are in Chile, though smaller deposits have been reported in California and Nevada. The commercial substance is prepared from the natural raw material by treatment with water. The nitrate dissolves and the earthy impurities settle out. The solution is then evaporated until the nitrate crystallizes out. Sodium nitrate is of especial importance for two commercial uses, the preparation of *explosives* and as a *fertilizer.* In the first instance it is the raw material from which nitric acid and potassium nitrate are prepared. In the second place it may be used directly as a nitrogenous fertilizer or in mixed fertilizers. In either case it is a valuable source of nitrogen, since nitrogen in this form is immediately available to plants.

Sodium tetraborate, borax, $Na_2B_4O_7$. Borax is found in some arid countries, as southern California. It is now made commercially from the mineral colemanite, which is the calcium salt of a complex boric acid. It has the peculiar property, when heated, of swelling to a great mass on account of the expulsion of the water of crystallization and then melting to a clear glass. This glass easily dissolves many metallic oxides and is, therefore, used as a *flux* in soldering to clean the surface of the metals. It is also extensively used as a constituent of enamels and glazes for both metal ware and pottery. In the household it acts as a mild alkali and is used to soften water, to preserve meats, and for a number of other less important applications.

POTASSIUM

Introduction. Potassium is a metal which much resembles sodium in its properties. Like sodium it never occurs free in nature, though its compounds are fairly widely distributed. Potassium compounds are important for several reasons. First, they are valuable for use in agriculture as fertilizers for the potassium contained in them. Second, they are of service in the arts on account of the other constituents contained in them. Potassium compounds are generally more costly than the corresponding sodium compounds. The chief reason is because the amount of easily accessible potassium compounds is far less than that of easily accessible sodium compounds. It is true, however, that the aggregate amount of these two substances in the earth's crust seems to be about the same.

Distribution. Potassium is widely distributed in combination with other substances, never in the free state. It occurs in many minerals and rocks. Orthoclase, a variety of feldspar, contains 14% of potassium. Rocks like granite contain some of these minerals. There are some natural deposits of salts which are rich in soluble potassium compounds. The so-called Stassfurt deposits in Prussia are the best known source of potassium compounds which are used for various purposes. Compounds of potassium exist in minute quantities in soils, being derived from the minerals and rocks of which the soil is composed. Natural waters, such as certain mineral springs and the Dead Sea and the ocean, contain very small quantities of potassium. Plants have the power of selecting potassium salts from the soil. The ashes of these plants contain the potassium, principally in the form of potassium carbonate. Wood ashes, especially, are important for the potassium they contain. Some animal products have considerable potassium in their structure. The greasy material of sheep's wool is an example.

Preparation. Potassium can be prepared in the same manner that the element sodium is, either by heating a mixture of potassium carbonate and charcoal or by electrolysis of the chloride of potassium. The latter method is the one most generally used at the present time.

Physical Properties. Potassium is a silvery-white metal. It is soft, easily cut with a penknife, and is the lightest metal except lithium. It melts and volatilizes very readily under the influence of a moderate heat.

Chemical Properties. Potassium is very active, even more energetic in its action upon other substances than sodium. It reacts with the oxygen of the air so quickly that it is difficult to see the bright clean surface of the metal when it is cut. It also decomposes water very readily, and gives enough heat to set fire to the hydrogen evolved by the reaction. For this reason it is always kept under kerosene or gasoline.

Compounds of Potassium. *Potassium hydroxide,* caustic potash, KOH. This substance is prepared by methods which are the same as those used for the preparation of sodium hydroxide. It resembles the latter substance very closely in its properties and is replaced by the sodium compound for commercial uses on account of the lesser cost of caustic soda.

Potassium nitrate, saltpetre and nitre, KNO_3. This compound is found in certain parts of India, as crusts in the earth. It also occurs in soils to a small extent. It was formerly made by decomposing animal refuse in the open air in the presence of wood ashes. Potassium nitrate is now largely made by a reaction between sodium nitrate and potassium chloride, both natural salts. Potassium nitrate is a colorless salt which forms very large crystals. It is stable in the air, and when heated it is a good oxidizing agent, giving up part of its oxygen quite readily.

The chief use of potassium nitrate is in gunpowder and fireworks. Enormous quantities of it are used in blasting powder as well as gunpowder. Some saltpetre is also used for the preservation of salted meats. The use of this compound in the explosives depends upon the nitrate part of the compound and not upon the potassium. But the corresponding sodium nitrate has the unfortunate property of absorbing water from the atmosphere and that of course prevents its use in the powders.

Uses of Potassium. The most important use of potassium compounds is undoubtedly in connection with agriculture. Since potassium is one of the elements absolutely necessary for plant life, and since it is likely to be deficient in certain soils, the element must be supplied to those soils before their maximum cropping capacity can be attained. Soluble potassium salts, such as the sulphate, the chloride, the carbonate, and occasionally the nitrates, are used for this purpose.

Potassium compounds are largely used for industrial purposes, but in these cases, with certain exceptions, the presence of the potassium is merely incidental. The compound employed is useful on account of the other element or elements present. The most striking example of this is the use of potassium nitrate in explosives, instead of the cheaper sodium nitrate. Another instance is the use of potassium dichromate instead of sodium dichromate in certain manufacturing processes. This is because the potassium compound is more easily secured in the pure form than the sodium compound.

CALCIUM

Introduction. Calcium compounds exist in nature in comparative abundance. The preparation, properties, and uses of quicklime have been known since the first century of our era. Calcium occurs in a number of different compounds, all of which are very useful to man. Building stones, and artificial building substances, are secured from natural calcium compounds. These compounds also have important agricultural uses.

Distribution. Calcium never occurs in nature in the free form. It is, however, one of the principal constituents of many minerals and rocks. Calcium carbonate is probably the most important compound of this element. It exists in nature in a number of different forms, such as limestone, marble, chalk, the shells of shell-fish, etc. Limestone is composed largely of calcium carbonate, the amount depending upon the purity of the substance. Another important source of calcium is the sulphate, the natural form being called gypsum. This substance is widely distributed in natural waters, in soils, and in salt deposits. Calcium silicate is a common constituent of many minerals and rocks. Calcium phosphate occurs in certain amounts in the soil, and in deposits. From all these minerals calcium finds its way into natural waters and the soil. It is also taken up by plants and is an essential part of the mineral portion of plant life. The bones of animals are composed of calcium phosphate in great part. It is easily seen, therefore, that calcium is widespread in nature and is very important for all life processes.

Preparation. Calcium may be prepared by the electrolysis of certain of its compounds, such as fused calcium chloride.

Properties. Calcium is a gray metal, considerably heavier and harder than sodium. It oxidizes on the surface in slightly moist air. It readily decomposes water at ordinary temperatures, but the action is not violent enough to heat the water and melt the metal. Calcium hydroxide and hydrogen are the products of this reaction. There are no important uses for the metal at the present time, but it may prove valuable in the future.

Compounds of Calcium. *Calcium oxide*, quicklime, CaO. This substance is readily produced by heating any form of the carbonate in a properly constructed furnace. The limestone, or other raw material, undergoes a loss of weight and changes its properties. By this method 100 parts of limestone give only 56 parts of quicklime, the difference being the carbon dioxide which is evolved by the heat treatment.

$$CaCO_3 \rightarrow CaO + CO_2.$$

The manufacture of quicklime is a most important industry on account of the extensive use of the substance in mortars and cements. The furnaces in which the limestone is strongly heated are called kilns. The older style of kiln had to be fired and cooled as each charge of limestone was changed to quicklime. The newer lime-kiln is so constructed that the process is a continuous one, limestone being charged in at the top of the kiln as fast as quicklime is removed from the bottom. A number of fire boxes are built around the base of the kiln and the hot gases are passed up through the mass of limestone. The carbon dioxide liberated in the process may be conveyed away through pipes for appropriate uses.

Pure lime is a white amorphous substance. The characteristic property of quicklime is its action upon water. It evolves a great deal of heat, sufficient in some cases to set fire to combustible material with which it may be in contact. This process is commonly called *slaking*. Calcium hydroxide is the result of the reaction.

$$CaO + H_2O \rightarrow Ca(OH)_2.$$

Lime not only combines with free water in bulk, but it also absorbs moisture from the atmosphere. For this reason it is sometimes used to help remove the dampness from cellars. Quicklime also has a strong attraction for carbon dioxide and absorbs this gas from the atmosphere, thereby returning to its original form of calcium carbonate.

$$CaO + CO_2 \rightarrow CaCO_3.$$

This double action of lime in absorbing moisture and carbon dioxide from the atmosphere is called *air-slaking*. Both calcium hydroxide and calcium carbonate are results of this process and the air-slaked lime is a white powder which will no longer slake with water. Another characteristic property of quicklime is that when heated intensely as in the oxyhydrogen flame, it gives a brilliant white light, commonly called the *lime light*. This light has been very useful for stereopticon lectures and theatrical purposes, but is being rapidly supplanted by the increasing use of electricity.

The chief use of quicklime is for preparation of mortar and cement. For these purposes the lime is first slaked with water and then mixed with sand in the proportion of one part of lime to three of sand. When the mixture is used as mortar for laying bricks and stone, a chemical change takes place gradually, requiring sometimes many years for its completion. This is commonly called the *drying* or *setting* of mortar and involves the gradual expulsion of the water used in making the slaked lime. Carbon dioxide is absorbed by the lime, giving calcium carbonate which binds the particles of sand together. The sand gives body to the mortar, prevents too much shrinkage, and makes the mortar porous so that the change into the carbonate can take place evenly through the mass.

Cement is another important building material which is made with the aid of lime. Limestone, clay and sand are heated until the mixture is partly fused, and the clinker then ground to a fine powder. When this cement is moistened with water, it sets to a hard stone-like mass. The setting of cement is due to the absorption of water and not to the absorption of carbon dioxide. The process can take place even under water, so that cement is particularly valuable for that kind of construction. It is becoming more and more useful for building purposes and can be used in a great variety of ways. It is often used in place of mortar for laying bricks. Mixed with crushed stone and sand it forms *concrete* which is used in foundation work. It is also used for making artificial stones or cement blocks, stone walks, and in fact any building material which was formerly made of wood or natural stone.

Another important use of lime is in the preparation of bleaching powder. This article is consumed in enormous quantities in the bleaching of cotton and linen goods. It has also been employed as a disinfecting and germicidal substance in sanitary work and the purification of water supplies for drinking purposes.

Calcium hydroxide, slaked lime, $Ca(OH)_2$. This compound, when pure, is a light white powder. It is slightly soluble in water, forming a solution called *limewater*, used as a mild alkali for medicinal purposes. A paste of the slaked lime in water is sometimes referred to as *milk of lime*. Calcium hydroxide is a relatively cheap and efficient alkali and is used in many industries whenever an alkali is needed.

In this way slaked lime is used in the preparation of ammonia, bleaching powder, and potassium hydroxide. It is also used to purify illuminating gas, to remove the hair from hides in the tanneries, and for making mortar.

Calcium carbonate, $CaCO_3$. This compound is found in the earth in a number of valuable mineral forms. Some of these are not markedly crystalline, while others do occur in quite definite shaped crystals. The non-crystalline or amorphous includes the following common forms: limestone (always impure), pearls, chalk, coral, and shells. Of these limestone is the most familiar and is a grayish rock usually found in hard stratified masses. Whole mountain ranges are sometimes made of this material. Marl is a mixture of calcium carbonate and clay. The other forms mentioned are largely calcium carbonate.

Crystalline calcium carbonate occurs in the following forms. Iceland spar is a very pure and transparent form. Mexican onyx is a massive variety, streaked or banded with colors due to impurities. Marble when pure is made up of minute calcite crystals. Stalactites and stalagmites are icicle-like forms found in caves. Sometimes calcium carbonate is found in needle shaped crystals, which are, however, unstable and change over to the other crystalline variety. In Figure 42 is shown a specimen of an interesting form of calcite, the bird's nest variety. This rock is made up of a large number of small rounded pebbles of calcium carbon-

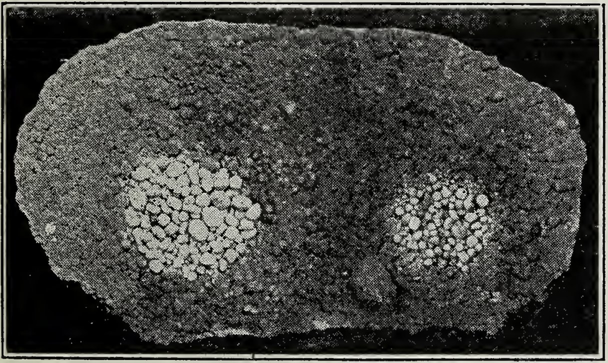


Figure 42.—Bird's nest calcite.

ate which were cemented together by some natural cement, probably acid calcium carbonate, $CaH_2(CO_3)_2$. In the center of the picture, some of the pebbles have been separated from each other and replaced without the cement.

In the laboratory calcium carbonate can be prepared by the reaction of a soluble calcium salt with a soluble carbonate. The product is a soft white powder, called precipitated chalk, and is used as a polishing powder, *whiting*.

Calcium carbonate, in its many forms, finds a host of uses; the preparation of lime and carbon dioxide, in blast furnace operations, in the manufacture of glass, soda, and crayon, for building stones and for correcting soil acidity.

Hard waters. When sulphates, chlorides and carbonates of calcium and magnesium are dissolved in water, the latter has the characteristic commonly designated by the term *hard.* Such a water may be *softened* by boiling, which removes part of the hardness, and by adding lye, washing soda, or borax which combines with all the soluble calcium and magnesium compounds and precipitates them from the solution. The boiling process causes any calcium or magnesium acid carbonate in the solution to be decomposed and calcium carbonate to be precipitated. The hardness caused by such material is called temporary, the other is permanent.

$$CaH_2(CO_3)_2 \rightarrow CaCO_3 + CO_2 + H_2O.$$

COPPER

Introduction. Copper is a very useful metal. It has been known and used for a long time on account of its wide distribution and the fact that it occurs in the free, or uncombined, form. It is comparatively easy to produce the metal from its ores. Copper is not only useful in the free form, but it is an essential constituent of many important alloys, as brass, bronze, etc. Some of its compounds also have industrial uses, and certain insecticides and fungicides contain copper.

Distribution. Copper occurs in nature widely distributed and in a large number of compounds. Some of the principal ores of this metal are free, or native copper, the oxides, carbonates, sulphide, and double sulphides of iron and copper. The United States produces more than half the world's supply of copper. The principal copper ore sections are the Lake Superior region, the Rocky Mountain region, and the southern, or Arizona region. Besides the United States, the greatest producers are Spain, Portugal, Chile, Germany and Japan.

Preparation. Copper is easily separated from its ores by one of a number of methods: by heating the oxides in a current of hydrogen, by heating the oxides with carbon, by precipitating the copper with a cheaper metal, such as iron or zinc, and by electrolysis of a copper salt solution. The extraction of copper from its ores upon a large scale depends upon the character of the ore. The processes aim to separate the copper compound from other impurities and form copper oxide, then to reduce the oxide by heating with carbon, and finally to purify, or refine, the crude product by electrolysis. The separation of the copper from impurities may be partly mechanical, such as washing the ore to remove earthy or rocky impurities, and chemical, such as oxidizing, or roasting, to remove the sulphur and arsenic which are commonly associated with the copper.

Physical Properties. Copper is a rather heavy metal with a density of 8.9. It has a characteristic reddish color, melts at 1084°C. and is rather soft, very malleable, ductile and flexible, but tough and strong. Its ductility is such that it may be drawn out into fine wire, which is largely used for mechanical purposes. Its toughness enables it to be beaten out into thin strong sheets. These may be employed in making copper vessels for a multitude of household and industrial purposes. Another characteristic property is its power to conduct heat and electricity, in which respe it is next to silver. Vast quantities of copper are now used for electrical purposes, both for making wire and apparatus. Copper is easily precipitated by electrolysis. Many uses are made of this fact in the arts, for example, the preparation of electrotypes, or the plates used in printing books, depends upon this principle. Copper is easily precipitated upon other metals in a compact form and serves to protect them.

Chemical Properties. Copper combines with a great many non-metals and forms a large number of important compounds. It gives two series of compounds, the cuprous, and the cupric. Copper also readily unites with other metals to form important *alloys.* Copper and zinc produce brass; copper, zinc, and tin produce bronze; copper and nickel give German silver; and copper and aluminium give aluminium bronze. Many other alloys of copper are known, all of which are useful for certain physical or chemical properties which they may possess. When exposed to the air copper acquires a thin skin of oxide which stops further corrosion. In this manner the chief portion of the metal is protected from further oxidation. This property is radically different from the rusting of iron; for in the latter case the oxidation progresses under the surface, so that eventually the entire object becomes rusted. When copper is heated in the air it is readily oxidized to black copper oxide. When exposed to moist air it slowly becomes covered with a thin layer of green basic carbonate, *verdigris.* Copper is fairly resistant to chemical reagents, being practically unaffected by hydrochloric acid, dilute sulphuric acid, and fused alkalies. Nitric acid and hot concentrated sulphuric acid do, however, dissolve it.

Cuprous Compounds. In this series the copper is univalent. Cuprous compounds are not as common as the other series, since they are easily oxidized into the latter.

Cupric Compounds. In this series the copper is divalent. Cupric salts are easily made by dissolving cupric oxide in acids or by precipitation. They are characterized by a blue or green color and crystallize well.

Cupric sulphate, blue vitriol, bluestone, $CuSO_4$, is a by-product of a number of processes and is produced in large quantities. It forms large blue crystals which lose their water of crystallization upon heating and the compound then becomes a white powder. The compound is very useful for electrotyping, in making electrical batteries, (See different kinds in Figure 43) and fungicidal preparations, as Bordeaux mixture.

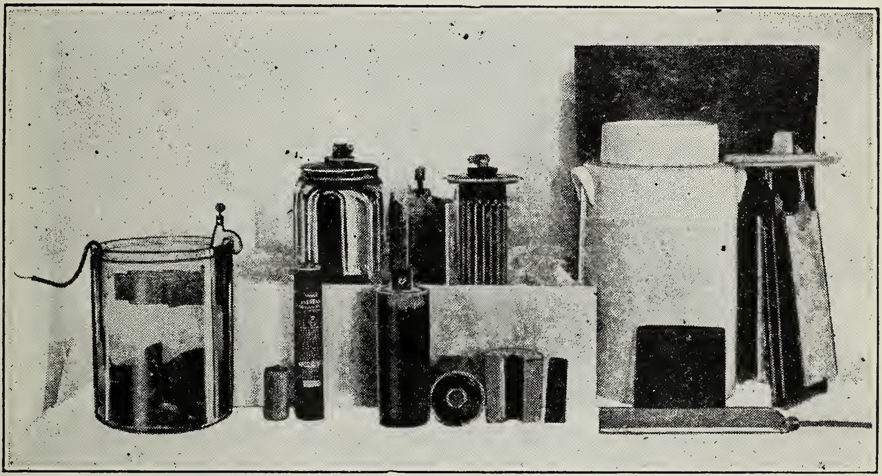


Figure 43.—Some common types of electrical batteries, including the Daniell cell, the sal ammoniac cell and the dry cell.

MAGNESIUM

Distribution. Magnesium is a very abundant element, occurring as the carbonate, sulphate, chloride and silicates. The double carbonate of magnesium and calcium is called dolomite; magnesian limestone is that in which part of the calcium carbonate is replaced by magnesium carbonate. Talc or soapstone, meerschaum, and asbestos are silicates of magnesium.

Preparation. This metal is prepared by the electrolysis of the fused double chloride of magnesium and potassium.

Properties. Magnesium is a rather tough silvery white metal of low specific gravity. It slowly becomes coated with a layer of the carbonate. It is less active than calcium, but decomposes boiling water with the evolution of hydrogen. It burns in the air with a dazzling white light. The ash of this reaction contains both the oxide and the nitride of magnesium.

Uses. Powdered magnesium is used in fireworks and in flash light powders in the ratio of 10 parts of magnesium to 17 parts of potassium chlorate.

Compounds. *Magnesium oxide*, MgO, is prepared by heating the carbonate and is called *calcined magnesia.* It is a white powder which is used for making crucibles and for lining electric furnaces.

Magnesium sulphate, Epsom salts, $MgSO_4$, is a common substance occuring in springs and salt deposits. It is used in medicine, the textile industry and some chemical works.

Magnesium carbonate, $MgCO_3$, is an abundant mineral. Its double salt with calcium carbonate, dolomite, is a very common rock, composing vast mountain ranges. It is harder and less readily attacked by acids than limestone, and is therefore, useful for roadbeds and building purposes.

Magnesium compounds are of considerable importance in the growth of plants. The element seems to be an essential constituent of chlorophyll and is present in the ash of the seed to a greater extent than calcium.

ZINC

Distribution. Zinc always occurs in the combined form. It is not widely distributed, being found in small areas. Its ores are the sulphide, oxide, carbonate and silicate of zinc.

Preparation. The ores are first roasted and the oxide thus formed reduced by means of coal dust. The zinc is volatile and may be distilled and collected.

Physical Properties. Zinc is a bluish white metal with a high luster. Its physical properties depend upon the temperature and previous treatment to which it has been subjected. When heated to a low temperature it is malleable, but becomes brittle at higher temperatures. At 419°C. it melts and with further heating it burns with a very bright blue flame.

Chemical Properties. The exterior surface of zinc metal is oxidized by moist air, but further oxidation does not take place. Zinc does not affect boiling water and when quite pure is barely attacked by acids.

Uses. It is used as a lining for water vessels and for *galvanizing* iron to protect the latter from rusting. Zinc is also used for making electrodes for the various types of electrical batteries. (See Figure 43.) Another important application is its use in *alloys*, examples of which are brass, an alloy of zinc and copper, the different bronzes, coin metals and bearing metals. When molten metals dissolve in one another freely, the results are called alloys. When mercury is one of the components, the name *amalgam* is applied to the alloy.

Compounds. *Zinc oxide*, ZnO, is a white powder and its principal use is as a white pigment in paint, when it is-called zinc white. It is not affected by hydrogen sulphide and is thus superior to lead paints which are turned black by that compound.

Zinc chloride, $ZnCl_2$, is often used to impregnate wood, as fence posts, railroad ties and telephone poles, and protect them against rotting. The chloride is a germicide and prevents decay.

IRON

Introduction. Iron is undoubtedly the most useful of metals. It is also one of the most widely distributed. It is an essential constituent of plants and of the coloring matter of blood.

Distribution. This metal occurs as oxides, carbonates, and sulphides in widely distributed ores. It is also found in the soil and in natural waters.

Preparation. Iron ores are reduced by heating them with coke or charcoal in a blast furnace. (Figure 44.) Such a furnace may vary in height from 30 to 90 feet and be constructed of firebrick reinforced with iron. Besides the charge of iron ore and coke or charcoal, limestone is also added. These materials are placed in the furnace in successive layers. When the furnace is fired a blast of hot air is forced in through the pipes at the bottom to increase the intensity of the reaction. The oxygen of the air unites with the carbon of the fuel in the lower part of the furnace and forms carbon dioxide, CO_2. This is reduced by the hot carbon further up in the furnace to carbon monoxide, CO. The latter gas combines with the oxygen of the iron oxide and iron and carbon dioxide result.

$$Fe_3O_4 + 4\ CO \rightarrow 3\ Fe + 4\ CO_2$$

The iron is drawn off through tap holes in the extreme bottom of the furnace and is run into molds, forming the bars called *pigs*, or it is transferred to the converters and made into steel. In order to remove the earthy impurities of the ore and the ash of the fuel, limestone is added as a *flux*. The limestone combines with such waste material and forms the glassy *slag* which is run off a little above the iron.

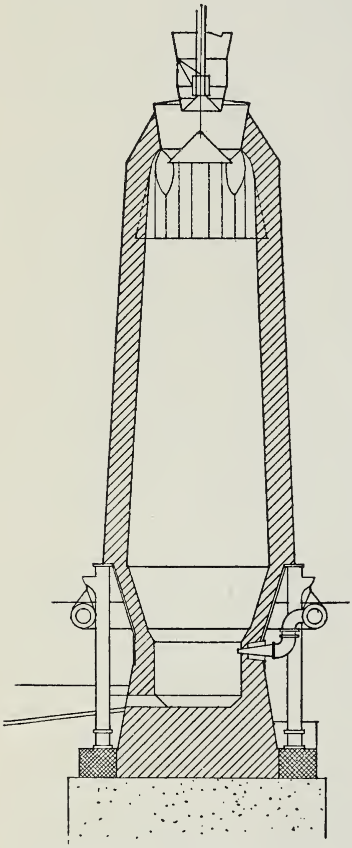


Figure 44.—A blast furnace.

Kinds of Iron. There are various grades of iron which differ from one another principally in the amounts of certain impurities which they may contain. These impurities are carbon, phosphorus, sulphur and silicon. The difference in the amount of carbon serves as a basis for the general classification of iron into the following three grades, *cast iron*, *wrought iron* and *steel.* Cast iron has from 1.5% to 7% carbon. It melts at low temperatures and is too brittle to be welded or forged. Wrought iron contains less carbon than either of the other two kinds, 0.6% or less. It is tough and malleable and requires a high temperature to melt it. It can be welded and forged, but not cast or tempered.

Steel contains more carbon than wrought iron, but less than cast iron. Its melting point is between the other two and it can be forged, welded, cast and tempered. Steel is manufactured either by adding carbon to wrought iron or heating cast iron and wrought iron together in a Bessemer converter or open hearth furnace. The converter is a large pear shaped furnace so arranged that blasts of air can be forced up through the mass. The air oxidizes the silicon and carbon in the steel and reduces their amount. In the open hearth furnace, pig iron is mixed with wrought iron and heated on a hearth with an oxidizing gas flame. The same result is achieved as in the converter.

Properties. Pure iron is not common. Wrought iron is the purest form in commerce. Wrought iron is ductile and a fairly good conductor. Steel is a very hard form of iron. Iron decomposes steam at a high temperature. It also rusts in moist air and carbon dioxide. Iron reacts readily with dilute acids. It forms two classes of compounds, *ferrous* and *ferric.*

Uses. Iron in its different grades is of fundamental importance in the progress of civilization. For the building of bridges and railroads, for the erection of factories and office buildings, for the manufacture of engines and machinery, iron has been the metal which has served man most in his various activities. This is partly on account of its great abundance, which makes it a cheap and readily accessible metal, and partly on account of its physical and chemical properties. Though iron is of the greatest importance and usefulness in the metallic form, some of its compounds are of value commercially and for plant and animal life.

ALUMINIUM

Introduction. About three fourths of the earth's surface is composed of silicon and oxygen and one third of the remainder is aluminium. These three elements have a great attraction for one another and are found in the form of silicates. On account of the great affinity of aluminium for oxygen and silicon, aluminium was not isolated in the pure elementary form until 1828.

Occurrence. Aluminium does not occur free, but is the most abundant and widely distributed metal in nature. Some of the most important minerals and rocks contain this element. Feldspar and mica are silicates of aluminium; granite is a mixture of quartz, feldspar, and mica; clay is a decomposition product of granite and similar rocks or minerals containing silicon and aluminium.

Preparation. Aluminium is manufactured by an electrolytic process somewhat as follows: The furnace consists of a box of iron lined with a mixture of coke and tar. This forms the negative electrode while the positive electrode consists of large carbons suspended by copper rods. A charge of cryolite, a double fluoride of aluminium and sodium, is used to start the furnace after which pure, dry, alumina is added. The process is continuous as the cryolite bath remains unchanged. The aluminium collects at the bottom of the furnace and is drawn off at frequent intervals. The oxygen unites with the carbon and forms carbon monoxide which escapes.

Properties. Aluminium is a white lustrous metal of low specific gravity (2.6), whereas the other common metals are from seven to nine times as heavy as water. It melts at about 660°C. and vaporizes at the temperature of the electric furnace. It is a good conductor, is ductile and malleable, and is capable of receiving a very high polish. At white heat, aluminium burns to aluminium oxide, Al_2O_3. Hydrochloric acid reacts with it, but nitric acid and dilute sulphuric acid do not ordinarily affect the metal. It reacts with salt solutions, if a little free acid is present. It is also soluble in the alkalies, sodium and potassium hydroxides, forming the aluminates of these metals and free hydrogen. Aluminium combines directly with the halogens and with carbon, silicon, nitrogen and some other elements. It does not tarnish in the air or when exposed to vapors containing sulphur.

Compounds. *Aluminium oxide*, alumina, Al_2O_3. This substance occurs in the form of the ruby, sapphire, and corundum. Emery is an impure form of corundum and is used for grinding and polishing.

Aluminium hydroxide, $Al(OH)_3$, is found as a natural substance, bauxite. This compound reacts with both acids and alkalies except ammonium hydroxide. The hydroxide is used as a mordant in the dyeing industry, that is, to fix the dye in fabrics which do not readily hold color.

Alums are double salts of aluminium sulphate with sulphates of univalent metals as potassium sulphate. Alums crystallize with 24 molecules of water of crystallization. Other trivalent metals may replace the aluminium in so called alums.

Uses. Aluminium is used in the manufacture of iron and steel to remove any oxygen the iron may have in combination and thereby increases the fluidity of cast iron and steel. It is also used as a conductor of electricity, in the manufacture of alloys, kitchen utensils and scientific instruments. Aluminium powder is used for flash lights and to reduce the oxides of many metals which cannot be reduced by carbon. A mixture of aluminium with various metallic oxides comes ready prepared under the name of thermite. When the mixture is ignited, the aluminium unites with the oxygen of the metallic oxide and liberates the metal. Much heat is liberated in the reaction and the process is used in welding operations where a large amount of local heat is required. In alloys the aluminium greatly increases the tensile strength of the metals with which it is combined.

Porcelain, stoneware, etc., are made from aluminium silicate, in the pure form called kaolin, in the impure form, clay. Porcelain is made by mixing kaolin with feldspar, shaping the mixture into the desired form and heating it to a high temperature. The more fusible feldspar melts and cements the whole together. Porcelain is hard and translucent and withstands the action of heat and chemicals better than glass. Stoneware is opaque, not having been heated as much as in the case of porcelain. Earthenware is made from common clay, hardened by heat but not fused. It is glazed by the addition of some common salt to the furnace at the time of heating. This vaporizes at the high temperature of the furnace and combines with the clay forming a covering of sodium aluminium silicate over the surface.

SUMMARY

The alkali metals constitute a group of elements which are somewhat similar in their properties. Sodium and potassium are the important members of the group to be considered here. They are very active, hence always occur in combination. These compounds are important for household, industrial, and agricultural purposes. Common salt, washing soda, baking soda and ordinary lye are examples of some common compounds of sodium. The compounds of potassium are of especial importance for use in agriculture as fertilizers.

Calcium occurs abundantly, but always in the combined form. Its compounds are found in the earth's surface and in plant and animal life. Calcium compounds are of great value to man since they are used in erecting buildings, in the chemical industries and in agriculture.

Copper is one of the oldest known metals. This is because it occurs in the free as well as the combined form. The refining of copper is an important operation on account of the vast commercial use of the element. It has properties which make it especially valuable for electrical work. It is also a constituent of many important alloys. Some of its compounds are useful, the chief one probably being copper sulphate.

Magnesium is a very abundant element and its compounds are important for commercial purposes and in plant growth.

Aluminium is the most abundant metal. Many natural minerals contain the element and its importance can be realized from the facts that its compounds form the bulk of the soil and are the chief material used in the manufacture of porcelain and stoneware. The metal itself has increasing commercial usefulness.

While zinc is not widely distributed, it and its compounds are of great value for the purpose of preventing the rusting of iron and the rotting of wood.

Iron is found practically everywhere. It is undoubtedly the most important metal from a commercial standpoint as it is used so largely for engineering and structural purposes.

QUESTIONS

1. State one important commercial use of each metal studied.
2. Name differences in the properties of sodium and potassium.
3. What substances studied are prepared from common salt?
4. What is the difference between washing soda and baking soda?
5. Why is the element calcium of importance to mankind?
6. State the cause of hard waters and means of softening them.
7. Compare the hardening of mortar with the setting of cement and plaster of Paris.
8. Why do caves often occur in limestone?
9. Give the chemical names and state the uses of the following: lye, common salt, saleratus, washing soda, wood ashes, Chile saltpetre and gypsum.
10. What is the difference between quartz and limestone; between gypsum and limestone?
11. Why is aluminum of unusual interest in connection with the study of the earth's surface?
12. Mention some important uses of aluminium.
13. Why is it necessary to produce a slag in the working of a blast furnace?
14. How may iron be protected against corrosion?
15. What is meant by the following expressions: electro-plating, slag, alloy?
16. Compare the properties of the metals studied.
17. What metals are prepared by electrolytic methods?
18. What commercial uses are made of sodium nitrate, sodium chloride and calcium carbonate?
19. Make a table showing the principal properties of at least five elements which are solids at ordinary temperatures.
20. Name as many chemicals as possible (which you have studied) that are usually found in the ordinary household.

CHAPTER VI

THE PLANT AND ITS PRODUCTS

Importance of the Plant. In preceding chapters we have learned about several important chemical elements and some reactions in which they take part. We are now occupied with the study of chemical properties and reactions of some materials very important in agriculture and daily life. None of these materials are more important than those produced by the living plant. Let us consider the reasons for the great importance of plants in agriculture. Have you ever assembled in your mind the sources of the various feeding stuffs of animals? It will be well to draw up as long a list of them as you can, remembering that man is included with the animals. You are acquainted, of course, with the uses of cotton, linen, flax and hemp fibers. Do you know their sources? Recall for a moment the sources of the various kinds of wood used in the manufacture of tools and furniture and in the erection of buildings. Can you not suggest many other ways in which plants are of service to man?

In some types of farming the plant itself is the chief product. This is true when the business is limited to the raising of grain or truck crops, such as wheat or onions. In live stock, dairy or general farming, however, the plant is rather a stepping stone to the chief product. In the form of various feeding stuffs it serves as a channel through which simple compounds of the air and the soil are converted into the complex compounds of meat, milk and other animal products. Let us try to see this relation more clearly as we proceed with our study.

Composition of the Plant. Before the processes of growth can be profitably studied it is necessary to become familiar with the composition of the plant. For this reason we will now consider the composition of the nearly mature corn plant, with ears glazed and ready for shocking. Table V. gives the average amounts of the most important organic compounds and of the chemical elements in 1,000 pounds of the plant.

Table V.—Important Elements and Organic Compounds of the Corn Plant

Pounds per 1,000 pounds of plant					
Water					790
Dry matter 210	Organic matter 198	Protein	18		
		Fat	5		
		Carbohydrates	175		
				198	
	Ash			12	
					210
					1,000
Hydrogen	in water		88		
	in organic matter		13		
				101.0	
Oxygen	in water		705		
	in organic matter		89		
				794.0	
Carbon				91.0	
Nitrogen				3.0	
Phosphorus				0.5	
Sulphur				0.1	
Calcium				1.2	
Magnesium				0.8	
Potassium				3.2	
Sodium				0.3	
Iron				0.2	
Chlorine				0.4	
Silicon				1.1	
Other elements				3.2	
					1,000.0

The water of Table V. is the amount lost by drying the plant at 100°C. Do you see any good reason for the use of this particular temperature? The loss includes water existing in the free state in the fresh tissues of the plant. It also includes water combined with other compounds in the plant, after the manner of the water of crystallization of certain salts.

The dry matter is the residue left after drying at 100°C. It consists of a mixture of organic and inorganic compounds containing the elements listed in the table. The ash, or ashes, is separated from the organic matter by a simple method which you will readily suggest. Care must be taken, however, to avoid volatilizing some of the ash constituents. A clear-cut distinction between elements that exist in organic compounds and those existing only in inorganic form is impossible. They may all, at some stage or other, be present in the plant in organic forms. From such compounds, as well as from the inorganic compounds, they would become ash constituents by burning.

Figure 45. Jean Boussingault, 1802-1887. This French chemist discovered that plants cannot take the nitrogen they need directly from the air. He also made some of the earliest chemical studies of the processes of growth in plants.

The organic compounds of the plant will be so important in our succeeding study of growth, that we must classify and study them at this point. The *carbohydrates* form the ground work both of the processes and of the products of plant growth. They contain *carbon*, *hydrogen* and *oxygen*. The last two elements are generally present in the proportion of two atoms to one, respectively. They occur in the same proportion in a very important and abundant compound. What is the compound? Do you not see the derivation of the term carbohydrate? The chief carbohydrates of the plants can be classified from the simple to the complex as follows:

Group 1—		
Monosaccharides	Dextrose	$C_6H_{12}O_6$
	Levulose	$C_6H_{12}O_6$
Group 2—		
Disaccharides	Maltose	$C_{12}H_{22}O_{11}H_2O$
	Sucrose	$C_{12}H_{22}O_{11}$
Group 3—		
Polysaccharides	Starch	$(C_6H_{10}O_5)x$
	Cellulose	$(C_6H_{10}O_5)x$

The compounds of the first group are called *hexoses,* from the number of carbon atoms they contain. They are also called monosaccharides because they are the simplest or unit compounds in the series. What difference do you observe between the two compounds in the second group? The term saccharide is derived from the Greek word for *sugar.* Do you see the significance of these prefixes?

Dextrose is common in small amounts in leaves, germinating seeds, flowers and fruits. On account of its great usefulness in the plant it never accumulates in large quantities. It is either burned as a source of energy or converted to some of the higher carbohydrates.

Levulose differs from dextrose in the structure of its molecule. Along with this difference go differences in chemical and physical properties. It occurs only in small amounts in some fruits.

Maltose occurs in small amounts in leaves, but especially in germinating seeds, where it is produced from starch. On boiling with dilute acids or by the action of the enzyme maltase it is converted into two molecules of dextrose. The nature of enzymes will be described when the chemistry of growth is discussed.

Sucrose occurs in large amounts in some plants, as in the stalk of sugar cane and the root of the sugar beet. It also occurs in many seeds in small amounts, and in leaves. In these cases, it is a reserve food of the plant. It is rapidly converted to starch in the ripening seed of corn, while in the sugar beet it is used directly for seed production in the second year of growth. By boiling with dilute acids or by the action of the enzyme invertase, this sugar is converted into one part each of dextrose and of levulose. The latter action occurs in the plant whenever sucrose is used.

Starch occurs in small amounts in leaves, but is especially abundant in the other organs, where it is a reserve food. It is most commonly found in seeds. Each kind of plant produces starch in the form of granules which are characteristic in size, shape, and markings. Some of these differences, as illustrated in Figure 46, make it possible to determine the source of foods by the aid of the microscope.

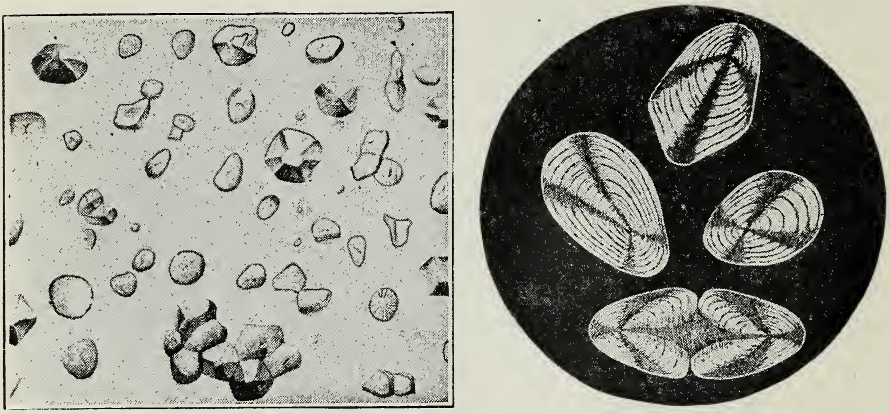


Figure 46. The appearance of granules of different starches under the microscope. Corn starch on the left, potato starch on the right.

Starch is not soluble in water, but by treatment with boiling water it forms soluble starch paste. This paste is converted to dextrose by boiling with dilute acids. The enzyme diastase converts it to maltose. In the formula for starch, the x following the brackets denotes that the molecule contains an unknown multiple of the unit structure within the brackets. What difference do you observe between this unit and the formula of dextrose? The preceding classification indicates only a probable difference in the value of x between starch and cellulose. Since *cellulose* cannot be converted to dextrose by boiling with dilute acids, however, we know its molecular structure differs from that of starch. This carbohydrate dissolves in strong acids, and, on boiling the diluted solution, dextrose and other sugars are produced. The enzyme cellulase converts it to soluble compounds. These differences show that the simpler carbohydrate units are modified differently in producing starch on the one hand, and cellulose on the other. The result is a more stable and resistant compound in the case of cellulose. This fits it for its uses of support and protection to the plant. Cellulose rarely occurs pure, although cotton fiber is pure cellulose. It is usually associated with other related compounds.

Have you noticed that, so far, we have described only ways for producing the simpler from the more complex carbohydrates? It is not yet possible to proceed in the opposite direction in the laboratry. Compare the formulae of the classification carefully and see if you can detect what general change occurs in passing in the one or the other direction. This change emphasizes the importance of a very common compound in the life of the plant. What is it?

Fats contain the same chemical elements as the carbohydrates. They are quite different from the latter, however, in chemical structure. These compounds are formed by the union of certain organic acids, the fatty acids, with the organic base glycerol, or glycerine. This base has three hydroxyl or basic radicles. The following equation expresses the formation of the fat acetin from acetic acid, the acid to which vinegar owes its sourness:

$$\underset{\text{Glycerol}}{C_3H_5(OH)_3} + \underset{\text{Acetic acid}}{3\,CH_3COO\ H} \rightarrow \underset{\text{Acetin}}{C_3H_5(CH_3COO)_3} + \underset{\text{Water}}{3\,H_2O}$$

In the preceding equation the acid hydrogens and the basic hydroxyls combine to form water. If we substitute

NaOH and HCl for the base and acid respectively in the equation, what product shall we have besides water? Can you now suggest a name for the chemical structure of fats? The old-fashioned home process of soap-making involved the boiling of waste fats with the leachings from wood ashes. In this process potassium of the potassium carbonate in the ashes replaces the glycerol of the fat.

Fats are present in plants mostly as reserves in the seed. They exist chiefly in the liquid state called *oil.* Castor oil forms about one half of the castor bean. Many other seeds contain so much oil as to be greasy to the touch. Name some. Recall the method by which the housewife "dry cleans" grease spots from clothing. Could it be used to remove the oil from seeds? As a means to appreciating the economy of fats as sources of energy for germination, calculate the percentages of carbon in starch and in olein. Olein, the chief fat of castor oil, has the formula $C_{57}H_{104}O_6$. Which compound will produce the more heat when burned? The oil of any plant is a mixture of several fats. These compounds are produced in the ripening seed from sugars of the plant sap. During germination they are cleaved by the enzyme lipase to glycerol and free fatty acids.

The *proteins* are very complex compounds. Besides the elements which occur in carbohydrates and fats, they contain nitrogen and sulphur. The kind called *nucleoproteins,* on account of their abundance in the nuclei of cells, contain *phosphorus* also. Proteins are most abundant in seeds, where, like the other compounds, they serve as food for the seedling. They are also necessary constituents of all living cells. By hot, strong acids and by the enzymes called proteases they are converted to simpler compounds. These products are *the amino acids and amides.* The former are related to both ammonia and the fatty acids and are weak acids. The latter are relatives of both ammonia and amino acids. They are neutral salt-like compounds.

Only small amounts of water-soluble proteins occur in the plant. Where these compounds are to be carried about, they are converted to amino acids and amides, or intermediate compounds, which dissolve in the sap. Some seeds contain four or five per cent of proteins soluble in strong alcohol. These compounds include *zein* of corn and *gliadin* of wheat. The latter is a constituent of the gluten to which the bread dough owes its important properties. By far the largest proportion of plant proteins are those soluble in weak salt solutions. They are called *globulins.* One of them, *conglutin,* forms about one fourth of the lupine seed. Of all the compounds of plants the proteins are most closely connected with the chemical processes of life. By the action of acids and enzymes, nearly twenty different amino acids and amides have been obtained from them. Some of these products are very complex structures. Thus, so far as complexity of the molecule is required, proteins are well suited to the varied chemical reactions which occur in life processes.

Of the many compounds found in plants but not included in Table V, we can take notice of but a few. The *alkaloids,* especially important in medicine, include quinine of a certain bark, morphine of the poppy, and nicotine of tobacco. They are bases of the same general structure as ammonia. *Waxes,* which form the bloom of certain leaves and fruits, are close relatives of the fats. They contain some other base than glycerol and only one fatty acid molecule in their structure. *Terpenes* are the chief constituents of pitches, turpentine, and rubber. A dictionary will help you to learn the source and uses of these substances. The *aroma* of many plants, such as the spice carnation, is due to terpenes and related compounds. The terpenes contain only carbon and hydrogen. Organic acids and their salts cause the sourness of many fruits and some leaves, as in the currant and rhubarb plants.

The ash, or ashes, of plants contains many compounds. The proportion of these varies with the kind of plant and the composition of the soil. All inorganic elements present in the soil are likely to be found in the plant ash, but, for reasons we shall learn later, they are not likely to be found in the same proportions in which they exist in the soil. The most abundant of the ash compounds are *silica*, *potassium carbonate*, *calcium sulphate*, and *calcium phosphate*. Silica exists in the plant in the free form and, as an inorganic or non-burnable constituent, is left in the ash. Calcium sulphate can be derived entirely from organic compounds, the calcium being contributed by calcium salts of organic acids and the sulphur by proteins. One can see, therefore, that the ash is not the inorganic matter of the plant.

Having surveyed the compounds of the plant, let us study the process by which they are formed.

The growth of the plant is the result of many chemical and physical changes. The nature of some of these changes is not well known.

You must have observed that some plants which grow upon decayed wood or leaves in shaded spots are nearly colorless. What is the most common plant color with which you are familiar? With this difference of color is associated a great difference of methods by which plants obtain their food. The green plants manufacture their food from carbon dioxide obtained from the air and water and salts obtained from the soil. Other plants obtain their food from either dead or living tissues of the higher green plants. The destructive rusts and smuts of grains are plants of the latter kind. Can you suggest others?

Chief among the processes of growth of the higher plants are the absorption of food materials, the formation and usage of foods, and the excretion of waste products. All of these processes occur simultaneously within the limits of units of the plant called cells. Some of the smallest forms of green plants, such as the *algae* which form slimy films on damp rocks, consist of a single cell each. In most cases, however, multitudes of cells are united to form tissues, such as wood and bark. These tissues are, in turn, related to form organs, such as the leaf and root. The burden of the processes of growth is distributed among these organs. A good example of the physical changes of growth is the movement of water through the plant. The formation of maltose from starch in germinating seeds is typical of the chemical reactions. The latter reactions, including many of unknown nature, form the basis of the fascinating and very important subject of *biochemistry*, or the chemistry of living things.

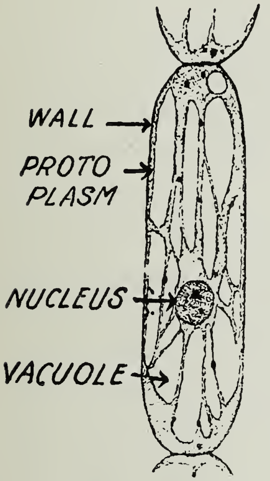


Figure 47. A plant cell and its principal parts.

Structure and Properties of the Plant Cell. The cells of the leaf hairs of the squash should be examined under the microscope. We shall then be better able to understand the reactions which occur in it. Figure 47 shows the structure of one of the cells composing such a tissue. What four organs do you find named in the figure? The structure of the cell may be roughly likened to that of a football, the cell wall corresponding to the cover, the protoplasm to the bladder, and the vacuole to the air space within the ball. In chemical composition, the walls consist of cellulose and related compounds, the protoplasm is a complex mixture of proteins and fats, together with other organic compounds and inorganic salts, and the vacuole contains sap. This sap is a solution of sugars, salts and other compounds in water. Suspended in the protoplasm is a body called the nucleus, which is especially important in the process of reproduction of the plant. It consists largely of nucleo-proteins.

The power of soft, succulent tissues, such as those of cabbage seedlings, to stand erect is due to the turgidity of the separate cells. *Turgidity* is caused by the presence of sufficient water in the vacuole to press the protoplasm against the cell wall and distend the latter like an inflated football. Have you observed how quickly young plants wilt on hot, dry days? *Wilting* occurs when the air takes water from the plant faster than the plant can get it from the soil. Each cell loses its turgidity and the whole plant collapses or wilts. When the condition becomes extreme, the protoplasm withdraws from the cell wall and shrinks to a spherical mass. This change is called *plasmolysis.* If long continued, it causes death. From what has preceded we should appreciate the importance of water and the protoplasm in the life of the plant. We should remember especially that the most important chemical reactions of the plant occur in the protoplasm. If one compares the plant with a busy chemical laboratory, as one may well do, the protoplasm may be regarded as an apparatus combining the uses of a crucible, a beaker, and a retort. From materials conveyed to it from without the cell, it produces foods. These are either burned as fuel to drive the machinery of the cells or used as structural materials in the processes of growth. As the plant ages new cells are formed to replace the old ones and to continue the growth and work of the tissues. Meantime, the older cells die and lose their contents of sap and protoplasm. The cell walls also gradually thicken on account of an increased production of cellulose compounds. This process, called *lignification,* modifies some cells so that they become practically solid and form dense wood.

The chemical changes which occur in the plant during the round of its growth from germination to fruitage will now be considered. It will be best to choose as the starting and finishing point in this cycle the stage when the plant is most nearly at rest. Can you not suggest what stage should be chosen? When the farmer plants his seed in the ground he hopes for the early rain which he knows will hasten germination and the appearance of his crop. Has it occurred to you how the rain acts to produce this result? Before answering this question one must consider the possibility that the seed may act upon the water also. It can be shown, indeed, that seeds take up water with great force; for, if dry pea seeds be suitably confined and then soaked in water, the power with which they will swell may be caused to lift great weights. This is due to the *affinity* of the seed and the water for each other. Both physical and chemical attraction between the compounds of the seed and the water enter into this affinity. Do you not see that this force must exceed the demand of the soil particles for water before the seed can derive its water from the soil?

When the seed has absorbed a certain amount of water the chemical changes of growth begin. The rate at which they proceed will be greatly influenced by the temperature, like other chemical reactions. Water alone, however, is not sufficient to supply the needs of germination. By testing the air surrounding seeds germinating in a suitable vessel it can be shown that carbon dioxide is produced. How would you make the test? The seeds *respire,* as do animals, in the process commonly called breathing. What element of the air is used in this process? Water absorbs much heat. Now, it is good farm practice to remove the excess of water and admit air by draining the soil. Can you not state two definite reasons why such practice favors germination?

Enzymes are very important in the germination of seeds. They are organic substances produced by the protoplasm. As it is not yet possible to obtain them in a pure state, their composition is unknown. Enzymes have peculiar abilities to cause various compounds to break into simpler units. In some cases they can build compounds from units. They cause various reactions, but the most common ones are those in which the compounds affected take on water before breaking up. This reaction is called *hydrolysis*. It is exemplary of the great importance of water in the chemical changes of growth. Each kind of enzyme can affect but one kind of compound. Thus, the enzyme which acts on protein cannot act on any other compound. These active substances are very sensitive to many chemical compounds and to heat. Some compounds affect them like poisons and temperatures of 70° to 80°C. permanently destroy their power. With proper conditions of temperature, moisture, and oxygen supply, the various food compounds stored in the endosperm of the seed are changed into soluble products. These products are taken from the sap by the embryo or seedling and used for growth in the manner already described.

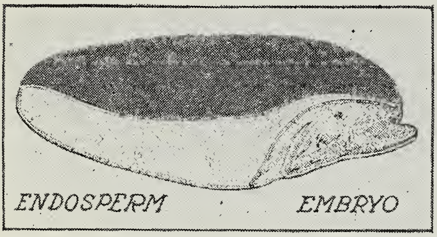


Figure 48. Section through a grain of wheat. The embryo is the future plant. The endosperm supplies it with sugar and the bran layer surrounding the whole supplies ash constituents. This endosperm is rich in starch. In some seeds the endosperm is rich in protein and fat.

After germination has proceeded a few days, one finds that a small plant with separate organs has been produced. Suppose the plant were kept in darkness. Would it grow to maturity? Would the food in the seed keep it growing? Under the usual conditions, the *roots* and *leaves* take up their work as organs of the plant. The *stem* is of service also, and later the *blossoms* and *fruit* appear and perform the work of reproduction.

Roots perform a very important service to plants by absorbing water and dissolved salts from the soil. Carefully remove a seedling of radish which has been grown in loose sand, and you will find a conical mass of the soil clinging to the root. On gently washing away this cone it can be seen that it was supported by short branches from the main root. These branches are called *root hairs.* They are confined to the growing part of the main root, just behind its tip. Figure 49 shows the relation between the two. Notice that each root hair is the arm of a cell on the surface of the root. It coils about the soil particles. Thus, if substances can pass through cell walls, they have direct channels into the plant through the root hairs.

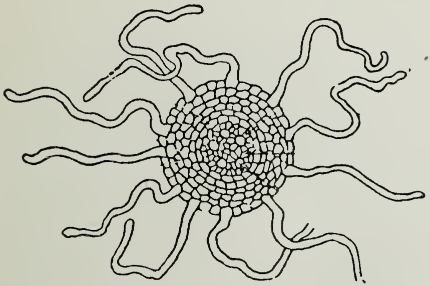


Figure 49. Section across a root. The contents of the root hairs finally reach the conducting bundles at the center and travel upward to the leaves.

Osmosis is one of the forces, which will cause water to move into plant roots. This force may be demonstrated by distending an animal bladder with water, closing tightly and immersing in molasses. After a few hours the bladder will be shrunken and collapsed. The affinity of sugar for water is so great that the molasses is thirsty. Sugar cannot pass readily through the bladder, but water can, and hence the latter is withdrawn from the bladder. The shrinkage of pickles and meats in brines is due to the removal of water by osmosis. When the sap of root hairs contains much dissolved matter, the root can take up water by osmosis. Root hairs also absorb water by the affinity of their cell walls and protoplasm for water. The entrance of salts into the root is not regulated by the entrance of water, but largely by the protoplasm. Sometimes this organ allows a given salt to pass through it, and again it does not. When any salt enters the cell it does so by the principle of osmosis, if its strength in the cell sap is less than in the soil solution.

The root is not limited to a selection from the salts of the soil water. It directly increases the amount of salts dissolved from the soil minerals by excreting carbon dioxide. This increases the solvent power of the soil water. The activities of the root which we have been considering, and probably others unknown, contribute to a selective feeding power of the plant. Have you noticed how rasping to the touch are the leaves of corn, barley, and many other grasses? This is due to their peculiar selection of silicon from the soil. On account of such peculiar ability also, the rutabaga and other cruciferae excel plants of other families in absorbing phosphates from the soil.

Figure 50. Showing that rape and buckwheat, on the right, can absorb insoluble phosphate better than corn or barley, on the left. Left hand jar of each pair contained rock phosphate; right hand jar contained acid phosphate.
Courtesy of E. Truog, Soil Dept. University of Wis.

The stem of the plant, together with its branches, is of chief interest to us as the *channel* wherein sap and water move. Have you ever noticed the threads which protrude from the pith when mature corn stalk is broken? They contain the sap and water channels arranged in bundles. In stems, which, like the corn stalk, grow toward the center, the less frequent, newer bundles toward the center are most active. On the other hand, in stems which grow outward by annual layers, like the common fruit tree, the active bundles occur only in the cambium or inner bark. Figure 51 shows the nature of the conducting bundles. Water travels upward in the large thin-walled vessels and the food-bearing sap travels about in the smaller ones. These bundles end, on the one hand, in the growing region of the root near the root hairs, and, on the other, in the loose tissue of the leaf or flower. The arrangement permits circulation in the plant. Some stems, such as the tree trunks, tubers, and bulbs, serve for the storage of starch and other foods. The reserve food in the underground stem of the quack grass makes this weed very resistant to tillage.

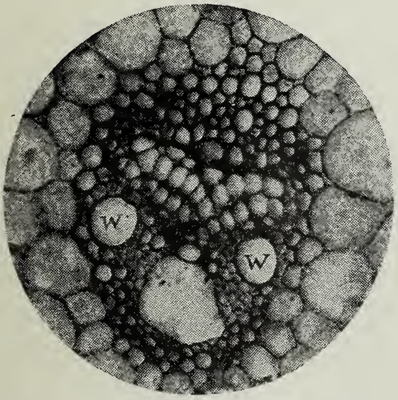


Figure 51. A conducting bundle of a stem. The large channels (w) convey water to the leaves. The smaller channels, grouped at the top of the figure, convey food-laden sap from the leaves to other parts of the plant.

The leaf is, from the chemist's point of view, the most interesting organ of the plant. This is because it frees the young plant from dependence upon the parent seed. When this organ emerges from the soil, two important processes set in: (1) The leaf loses water to the air. This loss is transferred toward the soil through the stem. It is finally balanced by entrance of water from the soil to the root. This introduces the absorption of water and nutrient salts by the plant, the first step independent of the mother seed: (2) The leaf turns green. This coloring is due to the production of the compound *chlorophyll* by the action of *light*. It requires the presence of *oxygen* and *iron*. The true life work of the plant now begins. When exposed to the light, chlorophyll has the peculiar ability to cause water and carbon dioxide to combine. We have traced from the soil to the leaf the course of the water necessary to this process. The carbon dioxide required enters the leaf from the surrounding air through the *stomata*. These are also the channels by which water escapes from the leaf to the air. A single stoma is shown in surface and side view in Figure 52. With the aid of the microscope you can readily find stomata on the peeled-off epidermis of any common leaf. With most leaves they are of greatest number on the under side. Note from the illustration that the opening of the stoma leads from the outer air into a chamber in the leaf. This chamber is surrounded by loose tissue. Carbon dioxide diffuses from this space into the leaf tissue and through the moist walls of the separate cells. Together with water it now comes under the influence of chlorophyll. The following equations may be written to express the chief result of this process, called *photosynthesis*:—

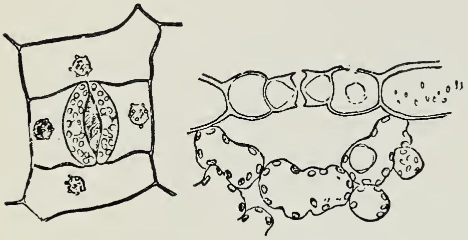


Figure 52. A stoma as seen under the microscope. On the left, looking at the surface of the leaf. On the right, looking at the edge of a leaf cut through the stoma.

$$CO_2 + H_2O \rightarrow \underset{\text{Formaldehyde}}{HCHO} + O_2$$

$$\underset{\text{Formaldehyde}}{6\ HCHO} \rightarrow \underset{\text{Dextrose}}{C_6H_{12}O_6}$$

Have you figured out the derivation of the word photosynthesis? The equations may not express just what occurs in the process. They are merely expressions of the most important steps which seem likely to occur in producing the first carbohydrate of the plant. As already stated, this carbohydrate is either burned as a source of energy or converted to reserve food compounds. It is not only important as fuel for the protoplasm, but it is essential to the formation of the building material, cellulose. When stored, it is converted to sucrose and then to starch. When seeds germinate the starch is converted to maltose and then to dextrose. What substance besides dextrose is produced in photosynthesis, as shown by the preceding equations? This gas is partly used in the leaf cells and partly escapes to the air through the stomata. There it balances some of the oxygen removed by combustion, animal respiration, and other processes.

By chemical changes within the plant many different compounds are produced from the carbohydrates. The most important of these are the proteins. In the formation of proteins, nitrates, sulphates and phosphates are reduced in the leaf cells. They are then combined with carbohydrates or their relatives to form unit parts of protein molecules. The important reserve fats of the plant are also derived from carbohydrates. In view of these processes, is it difficult to comprehend the great importance of the leaf to the plant?

The flower and fruit, forming together the reproductive organ of the plant, are the seat of rapid and complex chemical reactions. They utilize materials prepared by the leaf and brought to them in the sap stream. Dependent upon the nature of the plant, these materials are converted chiefly to starch, fat, or protein. These compounds are stored in the seed with the embryo of the future plant. During these processes much oxygen is absorbed and carbon dioxide is excreted. This is due to the respiration or burning of the protoplasm as it does its work. In some plants the heat produced in this way keeps the temperature of the flower considerably above that of the surrounding air.

The production of a mature seed is the great end of active plant growth. It does not, however, mark the end of physical and chemical changes. Respiration and attendant changes go on slowly in the seed so long as it is capable of reproduction.

Plant nutrition. The growing plant must be fed. Water and carbon dioxide are incapable of maintaining growth.

The plant must have food compounds from the soil. This can be shown readily by the failure of plants to grow in pure water. The study of what elements are necessary for the complete growth of the plant and how each affects its growth is called *plant nutrition.* This study has been followed chiefly by growing the plant in pure water or pure sand to which food salts have been added. This method is called *water or sand culture,* respectively. It has the advantage over the soil that one can know just what compounds are supplied to the plant.

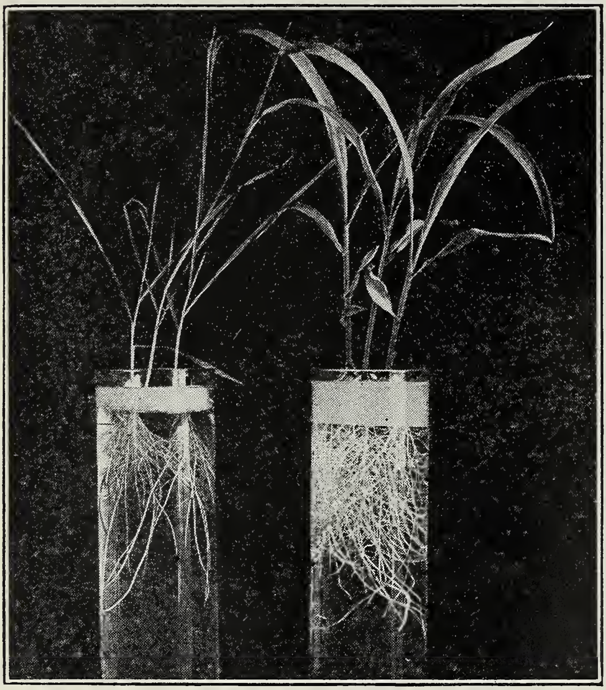


Figure 53. Young corn plants growing in water culture. On the left, in water only. On the right, with essential salts added.

The various elements found in plants grown in the soil have been divided into essential and unessential. An essential element is one necessary for the complete development of the plant from one generation to the next.

The water cultures illustrated in Figure 53 show the effect of a complete lack of some of these elements. Refer to the list of elements in Table V and check *sodium, chlorine, and silicon.* These are the *unessential* elements. All of the other elements of the list are *essential* to plants. *Nitrogen* causes vigorous, leafy development. *Potassium and* *calcium* are essential to carbohydrate formation and the building of cell walls. *Phosphorus* hastens ripening of the seed. You will find mentioned early in this chapter three very important compounds in which *magnesium, sulphur* and phosphorus occur. *Iron* is essential to the production of one of them. The unessential elements which you have checked are sometimes beneficial to plants.

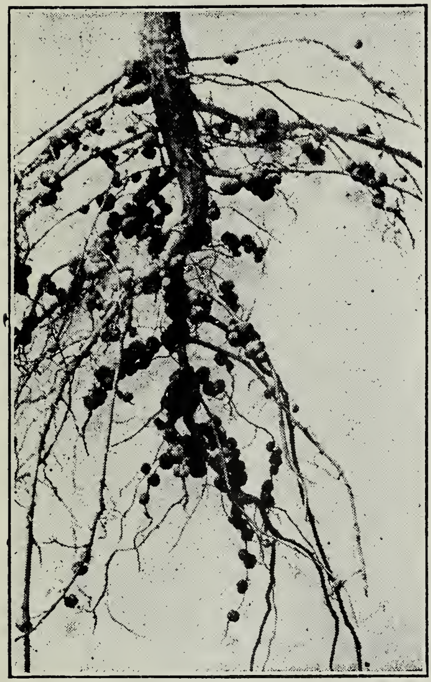


Figure 54. Root nodules on the roots of a soy-bean plant. By the aid of bacteria living in these nodules clover and the other plants of the legume family take nitrogen from the air in the soil.

Crops, or plants in bulk, as the farmers grow them, have different habits of growth and food requirements. Thus, the legumes obtain nitrogen directly from the air in the soil; but no other plants can do so. Alfalfa, clover, beans, and peas are leguminous plants. They support and nourish in nodules of their roots certain *bacteria*. These bacteria form nitrogen compounds from the soil air and present them to their hosts. Thus, while these plants need much calcium and potassium, they require practically no nitrogen compounds from the soil.

The cereal grains, such as wheat, barley, and corn, belong to the grass family of plants. This family is dependent upon manuring, and especially so for nitrogen. Barley and the true grasses are shallow rooted and soon exhaust the food of the surface soil. These crops need phosphorus for seed production, and they use much potassium. Where heavy leaf growth is most desired, as when they are cut immature for hay, the soil must contain a good supply of nitrogen compounds, These will form by the decay of legume crops or farm manure. Nitrate salts can be added also.

Root crops include the turnip, beet, and similar plants. These produce large amounts of reserve compounds and are heavy feeders. This fact is especially true of the mangel, a relative of the sugar beet. The root crops are very dependent upon the fertility of the soil for supplies of food materials. For the different species of beets, a deep, fertile soil is necessary. Many of the truck crops, such as the cabbage, and onion, resemble the root crops in feeding habits.

Fruit and nut trees and forest growth contain much reserve food materials in their trunks or stems. They draw chiefly upon this reserve for their growth from year to year. A large supply of food in the soil is thus unnecessary for these plants. The annual fall of leaves and twigs in the forest is almost sufficient. Small fruit plants, however, such as the strawberry, which have little reserve food, respond liberally to manuring.

Harvesting, to be conducted wisely, must occur at the time when a crop has *the highest food value.* With most of the grain crops this point occurs at full ripeness. At this stage the food materials of the stem have moved into the seed. The stem is then woody and indigestible. With true hay crops and cereal grains cut for hay, such as oats, the stems and leaves contain more protein and less cellulose at early blooming than at maturity. It is an economic loss to the farmer who does not observe this fact.

Corn differs from the other grains in that its most valuable constituent, starch, is stored in the seed rapidly at the last stage of ripening. During the period when the ears are glazing starch increases ten per cent in the plant, while the amount of cellulose remains unchanged. Whether cut for grain or silage, therefore, corn should be mature.

Silage is better, too, from mature than from immature, corn, because its composition changes less in the silo. What differences have you noted between the odor and flavor of corn and of silage? Those differences are due partly to *oxidation* in the silo. They accompany changes of sugar to acids and alcohols and the breaking down of protein. Such changes decrease the food value of the corn and should be checked. Will a loose, rickety silo check them? How will loose filling of the silo affect them? Even when air is excluded the living cells of the fresh silage continue to respire, using the oxygen of some of their compounds. Would this process continue longest in silage from mature or immature corn? The best quality and highest food value is secured by putting nearly mature corn into the silo.

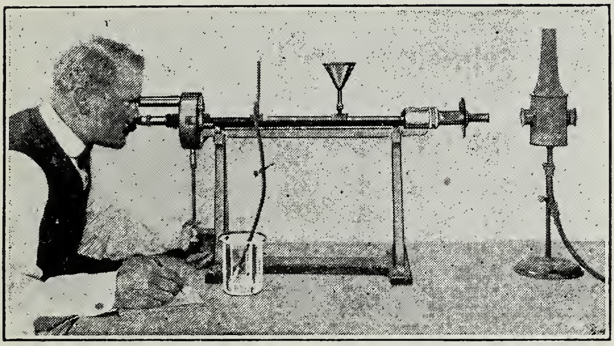


Figure 55. Measuring the amount of sucrose in sugar beets by means of the polariscope.

Exposure to rain and overhandling cause much loss of food value to hay crops. This loss is greatest with the value of clover and alfalfa hays. The delicate leaves of these crops easily rattle off when they are dry and brittle. Since the leaves contain more protein and much less cellulose than the stems, the hay loses most of its value in this way. Timely cutting and prompt curing are thus very important.

Means by which the composition of crops can be improved have been sought for many years. Man has been seeking to increase the amount of sugar in the sugar beet, the percentage of protein in wheat, and so on. At first thought it would seem that the amount or kind of fertilizers might produce desirable changes of this sort. It has been clearly shown, however, that the plant food in the soil influences the amount, rather than the kind of growth of plants. This is especially true of the seed, for the plant tends strongly to produce seed always of the same composition. If any food element is lacking, it produces less seed rather than seed of unusual composition. As a result of heredity, or the inheritance of qualities, a great deal of improvement in crops has been secured by selection and breeding.

Environment. Heredity is powerful; but it is not so powerful as environment in affecting the composition of crops. By environment we mean the climate; and climate consists of sunshine, rainfall, temperature, and other factors. No matter what the inheritance of the farmer's seed, no matter how he may fertilize, he cannot overcome the influence of environment upon his crop. To increase the sugar content of his sugar beets, for example, he must breed or select seed in the region, or climate, where he is to grow the crop. One of the most important effects of climate is due to excessive rainfall or irrigation. From hard wheat grains rich in protein this condition produces plump soft grains, rich in starch and less suited to bread-making. Temperature is especially important in the growth of sugar beets and sugar corn. These crops are favored by the temperate heat of the northern states of our country.

Rotation of crops has come to be known as a necessary feature of the successful farmer's program. Its value lies partly in the checking of particular diseases which increase where the particular crops which they attack are cultivated continuously. But it is also a means of greatly improving the physical condition and the fertility of the soil. After the growth of shallow-rooted crops, such as barley and turnips, the land needs the deep tillage required by the potato and mangel. When the deep-rooted mangel is harvested, its leaves return to the surface soil much plant food obtained from its deeper portions.

Have you observed any difference of prosperity between farmers who grow clover in crop rotations and those who do not? Perhaps you have asked your father or some prosperous neighbor why he grows clover in preference to common grasses. Not all successful farmers, however, know just why clover earns them profits. It is because this plant, like the other legumes, adds nitrogen compounds to their soils. The roots and stubble of one year's growth of clover or alfalfa on an acre of land leave fifty or sixty pounds of nitrogen in the first nine inches of soil. This is enough for a cereal grain crop. Peas and beans leave only a few pounds of nitrogen in their small root systems; but, when their tops are plowed in, they supply enough for one crop of any but the heaviest feeding truck and root crops. Can you learn from any helps how much that is? The importance of clover and other legumes on the farm should be plainly seen when one knows that other crops are helpless to secure free nitrogen from the soil.

SUMMARY

The plant serves as a factory for converting compounds of the soil and air into food for animals. When mature it contains sixty to ninety per cent of water. The other constituents consist of organic compounds and a little ash-forming material. Carbohydrates are the most abundant of the organic compounds. They are produced in the leaves and serve as food and building material. Fats are stored in seeds as foods. Proteins are stored also in the seed. They differ from fats and carbohydrates in that they contain nitrogen, sulphur, and sometimes phosphorus. The changes of life and reproduction are very closely dependent on proteins. Ash compounds are the remains of salts taken from the soil.

Active growth begins with the sprouting of the seed. First, the seed absorbs much water from the soil. Then, if the soil is warm and well aired, enzymes begin to act. These are substances which change starch and other foods of the seed to simpler food compounds. The embryo or young plant grows and develops the root, leaf and other organs.

The roots of plants absorb water and food salts from the soil. They have some power to select the salts taken up. Green leaves absorb carbon dioxide from the air. They also give off water to the air. This loss keeps water moving through the plant from the soil. Chlorophyll, the green compound of the leaf, forms carbohydrate from carbon dioxide and water in light. The stem and branches contain channels in which water moves to the leaves and sap moves from them. When the blossoms and the fruits are forming, the sap supplies them with food compounds.

Farm crops differ widely in habits of growth and of food requirements. In harvesting them it is important to choose that stage of growth when they have the highest food value. Silage undergoes some important changes due to respiration of the cells, or unit structures, of the immature plants. Climate, especially temperature, affects the composition of crops more than inheritance or the manner of feeding them. Crops should not be grown continuously, because such practice favors plant diseases and reduces soil fertility unevenly. Crop rotation prolongs the fertility of the soil and improves the crops. Clover and other legume plants are indispensable in crop rotations, because they supply nitrogen compounds to the soil.

QUESTIONS.

1. In what two conditions does water exist in green plants?
2. What is the composition of dextrose?
3. Of what use is sucrose to the growing plant?
4. How can the starch of different plants be distinguished?
5. What is the chemical structure of fats?
6. What two chemical elements not present in either carbohydrates or fats are contained in protein molecules?
7. Which of the plant compounds are most closely associated with chemical life processes?
8. Name five elements abundant in the ash of plants?
9. What are the chief organs of a plant cell? What is the composition of each?
10. What is the cause of wilting?
11. What are the nature and action of enzymes?
12. What organ of the cell regulates the entrance of soil compounds into the root hairs?
13. Name two elements which must be present for the production of chlorophyll?
14. Describe photosynthesis.
15. What chemical elements are essential to growth of plants?
16. What is the difference between legumes and other families of plants in regard to obtaining nitrogen?
17. Why should hay crops be harvested before maturity?
18. What process causes the chemical changes in silage?
19. What is meant by environment?
20. How does it influence the composition of crops?
21. Why are legumes especially important in crop rotations?

CHAPTER VII

THE SOIL

Origin of Mother Earth. At some time in the far distant past, according to astronomers, the material of our planet traveled through space as a mixture of gases. To human eyes on other planets, had there been such, it might have appeared like the nebular mists now visible in certain parts of the heavens through the telescope. This condition could exist, of course, only at very high temperatures, such as might be produced, for example, by the impact of two solid heavenly bodies. Gradually the gaseous mass cooled. As gradually, also, certain chemical elements with strong affinities for one another, but which had been kept apart by the intense heat, began to combine. Hydrogen combined with oxygen to form water. Silicon combined with oxygen to form silica. Calcium and oxygen combined to form lime. Silica and lime combined to form a mineral. Thus, one after another, various minerals were formed to produce a solid crust thrown into folds which retained the water. Such, in brief, is a widely accepted theory of the manner in which "Mother Earth" came into existence.

Appearance of Life. In the course of time, when conditions favored, certain of the chemical elements became associated in complex arrangements endowed with life. Perhaps living things first appeared in the water. The earliest form may have been much like the simplest creatures one now finds in pond water by the aid of the microscope. Suffice it to say that it must have been endowed by the Supreme Creative Intelligence with the chief powers still characteristic of living beings.

Formation of Soil. Finally some of the early forms of life attached themselves to the solid land for support. Here, by the waste products of their life processes and by the final decay of their own bodies, they contributed to the sum of chemical and physical changes which continually destroy and reform the soil minerals. Gradually there were established the living conditions necessary for the higher forms of life now so widely distributed in the plant and animal kingdoms. Thus the development of life has been largely dependent upon the formation of soil. Through countless ages the process has been the same—a ceaseless movement of material through chemical and physical changes. In large part these changes are biological, that is, they are caused by the living things inhabiting the material converted to soil. Is it not clear to you that the soil is a state of matter, rather than a fixed, unchangeable portion of matter? It is wonderfully like a living body in that it is continuously changing and renewing itself. This very process is what makes it fertile. On the one hand, rock and plant fragments are continuously undergoing destruction. Again, the products of this destruction are continuously being removed by draining away in water or by diffusing into the air. The mill in which these changes go on is what we commonly call "the soil."

As the home of the plant the soil has long been recognized as of the greatest importance to the maintenance of life on the earth. Until the time of the great Liebig, however, little was known of it in a scientific way. In recent years study of the physics and chemistry of the soil has shown it to be one of the most complex subjects in the realm of science. Not only are its compounds numerous and still partly unknown, but it is the medium of almost endless physical and chemical reactions. It would be better, could we do so, to avoid so complex a subject at first. Yet, since knowledge of the soil is so essential to our further study, we may best consider here its most important features in a simple manner.

In your daily labors and walks in the fields have you found the appearance of the soil the same from place to place? Perhaps you have been accustomed to using the names sand, clay and muck for soils quite different in appearance. Too often, though, these names are used to explain differences in the soil which are only vaguely understood. There are still too many persons to whom the soil is merely "dirt," personal contact with which seems degrading. To the keen minded country boy or girl, however, there can be no object more wonderful and interesting than the soil, rich in variety of minerals and teeming with living things and chemical action.

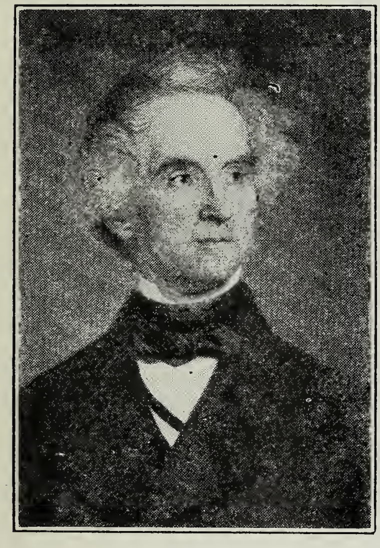


Figure 56. Justus von Liebig, 1803-1873, "Father of Agricultural Chemistry." He first conceived the idea that the soil feeds the plant and that it should be fertilized.

Relation of Rocks and Plants to Soil. To an observant mind it is pretty plainly evident that the rocks and stones continually cropping to the surface of the soil in tilled fields must have some common relation to the soil. Has it occurred to you, also, that the plants which die and fall to the ground year after year in marshes and swamps may have some relation to the deep black soils formed there? By the aid of the microscope one can see plainly that the finer material of fertile soils does, indeed, consist chiefly of minute fragments of rock and of plant tissues. The mere presence of these materials does not, however, guarantee a fertile soil. In order to contribute to fertility they must be undergoing processes of decay which free the essential elements which they contain. These elements, too, must be released as parts of simple compounds which plants can absorb for food. Processes of this kind are continually going on in fertile soils. Some are caused by physical forces, such as pressure or heat. Others are caused by chemical forces, such as oxidation. The chemical forces are due chiefly to the living things that inhabit the soil. Earthworms and larger animals take part in them, but the especially active agents are bacteria. We may call these living things biological agents in fertility. They must be favored by proper physical and chemical surroundings, if the soil is to be kept fertile. Thus, while the successful farmer must be a practical engineer in the tilling and draining of his soils, he must also be somewhat of a physicist, chemist and biologist combined. It does not require much reflection for one to realize that profitable husbandry of the soil requires no small degree of skill.

Before taking up the study of the physical and chemical changes which occur in the soil it is necessary that we equip ourselves with information about its most important constituents. For convenience, these may be divided into inorganic constituents derived from rocks and organic materials resulting from the decay of plants and animals. We must not suppose at all, however, that these materials exist separately in the soil. On the contrary, as decay goes on the products formed from inorganic and from organic matter combine with each other in intricate ways.

Soil Minerals. Can you recall whether or not most of the stones you have picked up from time to time have looked uniform in color and texture, as though composed of one substance? If not, examine some at your first opportunity. You will find that some of them consist very plainly of bits of different kinds of rock cemented together by yet other kinds. These separate constituents are minerals. In some places, as in the iron and copper regions, they occur in great masses. One can distinguish the different minerals by differences in hardness, color, weight and other properties. The study of these differences belongs to the special subject of mineralogy. A list of the most important soil minerals will now be given. In order that you may learn their general composition and what essential elements, if any, they supply to plants the acid and base forming elements which they contain are given in separate columns. What class of compounds have you become familiar with in your earlier study which is formed when acids unite with bases? From the number of elements present in some of these compounds of the soil you can see that they must be quite complex.

Table VI.—Soil Minerals and Their Constituents

Mineral	Base Forming Elements	Acid Forming Elements
Quartz	None	Silicon
Kaolinite	Aluminium	Silicon
Talc	Magnesium	Silicon
Feldspar	Aluminium and Potassium Aluminium and Sodium or Aluminium, Sodium, Calcium	Silicon
Mica	Aluminium and Potassium or Aluminium, Potassium Magnesium, Iron or Aluminium, Sodium Magnesium, Iron	Silicon
Selenite	Calcium	Sulphur
Apatite	Calcium	Phosphorus and Chlorine or Phosphorus and Fluorine
Calcite	Calcium	Carbon
Limonite	Iron	None

Let us compare the common properties of these minerals.

Quartz or silicon dioxide is a very hard and insoluble, crystalline mineral. Flint is a form of quartz. The mineral varies from white to black, and some varieties, such as rose quartz, are beautifully colored by traces of iron compounds or other impurities. It occurs frequently in great masses and is estimated to form about one third of the solid material of the earth's crust. Sand consists of small fragments of quartz rolled smooth by the action of moving water. Does the composition of quartz give you any clue to the reason why sandy soils are infertile?

Kaolinite, hydrated silicate of aluminium is one of the softest of minerals. It is white to yellowish in color. It is the chief constituent of clay soils. By its peculiar affinity for water it greatly influences the texture of the soil. It thus causes clay soils to "puddle" to a pasty mass when thoroughly wet. The behavior is a useful one in the pottery and brick industries but quite the opposite in soils. Does kaolinite supply plant food?

Talc, magnesium silicate, is a very soft mineral. Since all other minerals scratch it, its hardness is taken as the standard in mineralogy and given the value of unity, or one. It is white to green in color and feels soapy to the touch. The soapstone commonly used in making furnaces, sinks and laboratory table tops is a variety of talc. It is estimated that talc forms about 5 per cent of the minerals of the earth's surface. It is slowly decomposed by the soil water.

Figure 57. Photomicrograph of oligoclase, a sodium bearing feldspar, showing the composite character of some minerals.
Courtesy Prof. A. N. Winchell.

Feldspar is a group name of several minerals which are very important in the soil. They are the chief minerals of many kinds of rocks, but especially granite, where they are commonly associated with quartz and mica. The most important feldspar is orthoclase. This is a silicate of potassium and aluminium. It is a hard, flesh-colored mineral. It is much more soluble in water than either quartz or kaolinite. Can you not suggest why such a property contributes to the formation of fertile soils from feldspar? The feldspars are estimated to form about one half the minerals of the earth's crust. Many other silicate minerals are closely related by composition to the feldspars.

Mica is the group name for several rather soft minerals which are much less soluble than the feldspars. These minerals are polysilicates. That is, the acid portion of their molecules consists of a multiple of the simple silicic acid molecule. This is the cause of their capacity to hold several base forming elements together.

The most characteristic property of mica is the readiness with which it splits into sheets. You may have seen sheets of the mineral, gray to black, fitted into the upper walls of coal stoves. The different varieties of mica may form together one twelfth of the earth's minerals. Can you suggest why they are important in soils?

Selenite is a soft, rather light mineral and white to reddish in color. It occurs in small crystals in nearly all rocks. In some places it occurs in masses. This form of it, called gypsum, is pulverized to form "land-plaster." Selenite is much more soluble than any of the minerals we have studied. One pound of it will dissolve in 400 pounds, or about 400 pints of water. It is hydrated calcium sulphate. What important essential element not present in the previous minerals is supplied by selenite?

Apatite is of various colors, but most commonly gray. It is heavier than the minerals thus far studied, having a specific gravity of 3.2. In hardness it ranks next to feldspar. It is more soluble than quartz, but less soluble than mica. Its crystals are scattered through the older rocks. In places it occurs in masses and is quarried for fertilizer production. Apatite consists of tri-calcium phosphate crystallized with either calcium chloride or calcium fluoride. What do you judge to be the chief value of this mineral to the soil?

Calcite, a form of calcium carbonate, is a white mineral occurring in crystals about three times as hard as talc, but only half as hard as feldspar. Limestone, chalk and marble are of the same composition as calcite. The first two represent the accumulated shells of various shellfish. Marble has been formed from such deposits by the action of pressure and heat. Calcite is only a little more soluble in water than is feldspar. If water is saturated with carbon dioxide, however, it can dissolve thirty times as much calcite as when pure. If the carbon dioxide escapes from the water, most of the calcite separates from solution. This is the way in which limestone had been removed from some places and built up in others to form fantastic caves, such as the famous Mammoth Cave of Kentucky. This process is common on a small scale in fertile soils. On account of the weakness of carbonic acid there is a great tendency for calcite to react with any acids which may get into the soil. What change do you think occurs in these reactions?

Dolomite, is a mineral consisting of a mixture of calcium and magnesium carbonates. It is estimated that calcite and dolomite together form about 1 per cent of the earth's solid crust.

Limonite is a hydrated oxide of iron. It does not occur in crystals, but in irregular lumps of a brownish color. It has the same composition as iron rust. The mineral is hard, has a specific gravity of 3.6 to 4.0 and is brown to yellow in color. It forms the chief coloring matter of soils. Has it any food value to plants?

The various soil minerals have been more or less broken away in fragments from the original parent rocks during past ages. These fragments have also been cemented together in some cases to form newer rocks. Prominent among these rocks are the sandstones. The cementing mineral may be calcite, kaolinite, limonite or quartz.

Humus. Organic matter, or the material called humus, is as essential to the fertile soil as any of the minerals. This dark, spongy material results from the partial decay and oxidation of the mixture of organic compounds added to the soil minerals by plant remains, farm manure and similar materials. Surely you must have had an opportunity to observe the surface of vertical cuts in the soil like those made for ditches. Have you noticed any difference in color between the surface soil and that raised from a depth of a foot or more? Sometimes one can find a quite sharp line of separation where the dark soil is replaced by lighter colored soil. The lighter colored soil is lacking in humus. Organic matter has not reached a depth of more than a few inches in some soils.

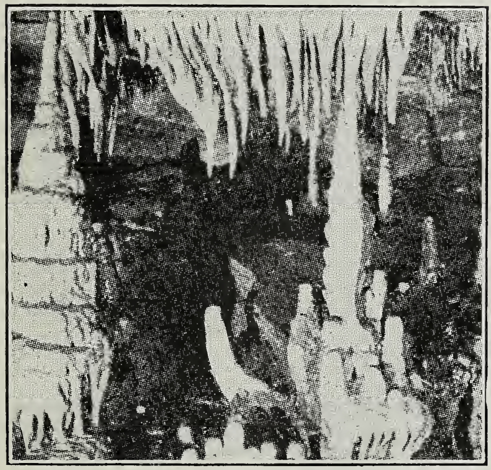


Figure 58. A Limestone Cave. The hanging stalactites and the standing stalagmites consist of calcium carbonate deposited from solution in water as the carbon dioxide escapes.

Much attention has been given by chemists in recent years to the study of humus. Many waxes, resins, organic acids, carbohydrates and nitrogenous compounds resulting from the original organic matter and its decomposition have been separated from it. The most important physical properities of humus are its gumminess and its power to absorb water. By the former property it binds the mineral particles together. The most important chemical properties of humus are its affinity for oxygen and the presence of nitrogen in its compounds. Products formed in its oxidation help to dissolve soil minerals for plants. As a source of nitrogen for plants it is of very great importance. For this reason clover and other legumes, which contain more nitrogen than grain and root crops, make valuable humus. Humus has also important biological properties. Chief of these is the support and nourishment it provides for bacteria and other organisms which increase the fertility of the soil. It is a material fairly throbbing with life processes and ceaselessly astir with chemical reactions. As a result of these conditions organic matter loses its independence as soon as it is tilled into the soil, the products of its decay combining more or less with the minerals to form humus.

Pulverizing Agents. Before the chemical changes which make fertile soils can proceed rapidly the coarse rock fragments must be pulverized. This process has been accomplished in past ages and is proceeding at present by the action of several physical agents. The glaciers accomplished a great deal of this work in the northern part of our own country. Grinding rock upon rock with enormous pressures as they moved down across the continent, they left large areas of pulverized soil minerals either spread or piled in their wakes as they melted back. The soils so formed are among the most fertile.

Ice is still an active agent in soil formation on a smaller scale. When the earth is moist the cracks and crevices in stones and rocks become filled with water. In freezing weather this water is changed to ice right in the crevices. Now, from your study of physics what change of volume do you know to occur when water freezes? The force produced in this way is very great and splits rocks to fragments.

Rapidly running water and winds of high velocity also contribute gradually to the making of soil. The moving water grinds stones upon one another or along the bed of the stream, and the wind hurls sand particles against cliffs and rocks. In these ways fine material is slowly ground away from the surface of rocks. This material may be carried along by the water or wind and deposited to form soil in some new place.

Plants and animals also help in the disintegration of rocks. The roots of trees are especially effective. They often penetrate cracks in rocks and then split them apart by their great power of growth as they enlarge. Earthworms are especially active in stirring the soil particles about and ants accumulate the finer soil particles to form their homes.

Temperature causes changes also, because it produces an unequal expansion and contraction of different minerals, sets up powerful stresses in rocks and causes them to go to pieces.

Let us turn for a moment to some principles met in the chemical laboratory. Which will dissolve quickest, a quantity of coarse rock salt or the same quantity of salt pulverized to a fine powder? How would you expect the same

Figure 59. The production of scil from limestone rock by physical and chemical forces. Limestone makes fertile soil.
Courtesy of W. O. Hotchkiss, Wis. Geol. Survey

difference of condition to affect the rate of decay of organic matter? The same principles apply to the soil minerals and to humus. That is why the physical changes which disintegrate rocks are so important in the making of soil. The chemical changes which make food materials available to plants proceed more rapidly in fine than in coarse mineral particles.

The texture of the soil is very important in the growth of crops. This is because the texture controls to a great extent the power of the soil to hold water, its content of air and the rate at which the minerals dissolve. Would you expect the more oxygen to be at hand for the oxidation of humus material in coarse sandy soil or in compact clay soil? Do you not see that here is a relation important in the fertility of the soil? A soil consisting of fine particles will hold more water than one of coarse sand. In the finer material there is more total surface on the soil grains than in the sand. For example, one cubic inch of space will contain 1,000,000 spheres each 1-10 inch in diameter the total surface of which will be 314.2 square inches. Let the diameter of each sphere be 1-1,000 of an inch, however, and the cubic inch will hold 1,000,000,000 of such spheres the total surface of which will be 3,142 square inches. The particles of a fertile soil are covered with a film of water attracted to them and held by a physical force called absorption. From what has just been said would you expect the fine or the coarse soil to hold the more water? Furthermore, the finer soil particles make much closer contact than the coarser ones. The strength of the films of water is thus increased, so that the whole mass of water in the soil moves rapidly to the surface to replace that removed by plants or lost by evaporation. The rise of water in this manner, as in tubes of very small bore, is called capillarity? Do you see herein any explanation of the beneficial effects of frequent shallow tillage during dry seasons and in regions where dry farming must be practiced? There is another advantage in fineness of the soil minerals. By the more thorough contact with the soil water more plant food material is dissolved for the plant than in coarse soils.

The physical properties of the soil, such as its power to absorb water and heat, depend directly upon the properties of humus and the minerals. They also depend upon the proportion in which these different constituents are present. If we were to cut cubes of equal size from dried sand, clay and peat we would find the peat about one third heavier than water, while the sand and clay would each weigh about twice as much as the peat. These differences are directly due to the differences of specific gravity between the chief constituents of the three soils, which are quartz, kaolinite and humus respectively.

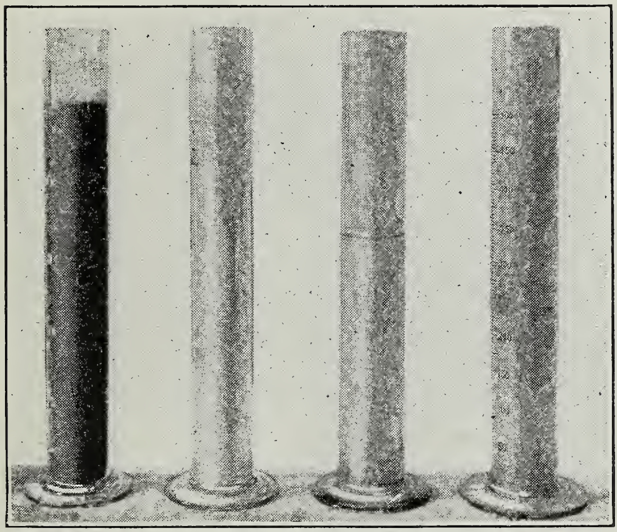


Figure 60. The power of soils to absorb water. At the left is a cylinder of dry peat. The next cylinder contains the amount of water it can absorb. The third cylinder contains the amount of water that dry clay of the same volume as the peat can absorb. The fourth cylinder shows the amount of water which medium fine sand can hold.

If we were to immerse the bottoms of these cubes of dry soil in water and let them soak up the liquid until they stopped gaining weight we would find important differences. In this volume of one cubic foot, which is about 48 pints, the sand would take up 22 pints of water. The clay would take up 33 pints and the peat 40 pints. So we see that the clay and peat soils hold water far better than sand. But this is not all in their favor, for they also retain the water more strongly than sand. In this way they withhold it from the plant. Plants will, therefore, wilt upon the clay and peat, while they still contain about 9 pints of water per cubic foot. The water content of sand, on the other hand, will fall to about 3 pints per cubic foot before plants will wilt. Given a sufficient supply of plant food material in them, which of these types of soil would you select in a region of low rainfall? Clay soils often take on, when wet, the "puddled" condition mentioned in discussing kaolinite. They can be made porous by adding lime. This process of rendering soils porous is called flocculation.

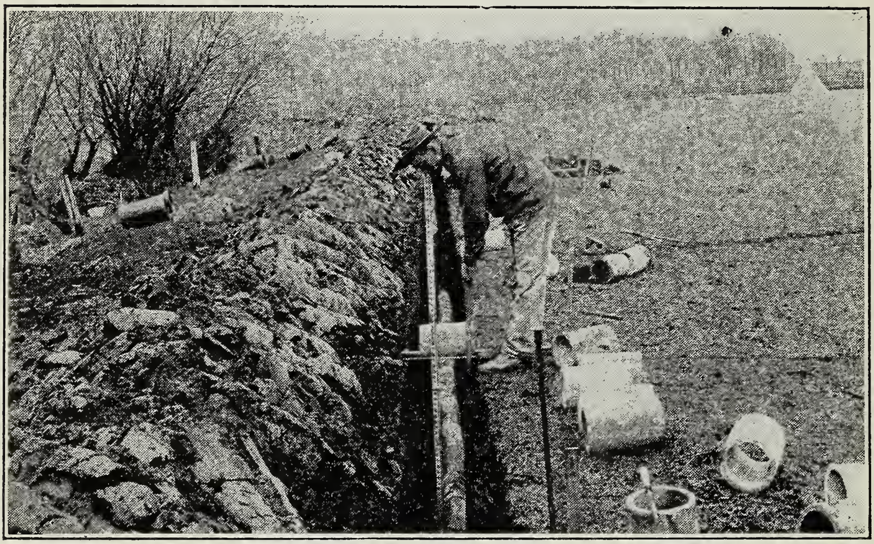


Figure 61. Laying tile drains to warm and ventilate the soil.

The heat absorbing power of the soil depends chiefly upon its water content. This is due to the high specific heat of water. As you may know, it is taken as a standard for measuring heat absorption in physics and given the value one. For equal volumes of the materials sand absorbs only one half as much heat as water, and clay and humus less than 0.6 as much. Is any further evidence necessary that the amount of water present largely determines the temperature of a soil? Wet soils are notoriously "cold" and late in producing crops. Their only cure is drainage. This not only warms the soil but admits air, which replaces unfavorable by favorable bacterial processes and chemical changes. Can you not suggest reasons for the high favor in which sandy soils stand among growers of early truck crops?

The chemical properties of soils depend upon the kinds of compounds and reactions most common in them. These reactions are most rapid and extensive in the humus. Oxidation is the most important of them. It may be either complete or incomplete, depending upon the supply of oxygen in the soil. When it is complete, the elements of the organic compounds in the humus forming material are set free,—carbon as carbon dioxide, hydrogen as water, nitrogen as nitric acid, sulphur as sulphuric acid, and so on. As a matter of fact, though, parts of some of the organic compounds resist oxidation for a long time. These form a large share of the dark, spongy material called humus. All the products of oxidation are extremely useful. The carbon dioxide may escape to the air and become the source of carbon for plants. It may also remain dissolved in the soil water, greatly increasing its power to dissolve minerals. We have already considered its action upon limestone. Selenite, apatite and feldspar are two to three times as soluble in carbonated water as in pure water. By the action of carbon dioxide in solution upon feldspar potassium is made soluble as the carbonate, and kaolinite is left as a residue. By further long continued action the aluminium is removed from this mineral and only quartz remains. In this way clay and sandy soil are formed successively from feldspar-bearing rocks, such as the granites. As the potassium is gradually removed the soil becomes poorer, until pure, infertile sand is reached. Of course, it takes hundreds of thousands of years for a granite rock to pass through these changes. The most important fact is that useful elements are ceaselessly being prepared in this way for the feeding of plants.

The oxidation of organic matter in the soil is caused chiefly by bacteria. These organisms are equipped with a whole arsenal of enzymes for this attack. Both the life of the bacteria and the chemical changes they produce are favored by the warm temperatures of the summer months. Hence their useful products are formed in the soil at just the season when the growing plants need them.

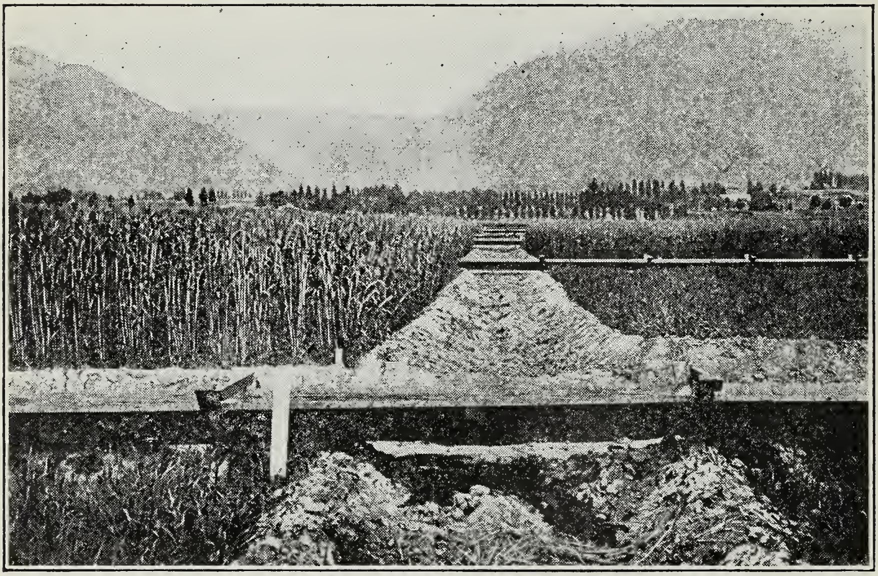


Figure 62. Irrigating crops in the dry climate of Utah.

Nitrification is the particular oxidation process by which nitrogen is changed to nitric acid. Special kinds of bacteria cause it. It is especially important, because it is the only source of nitrogen for all plants but the legumes. Furthermore, perhaps no other chemical element, even carbon itself, is more necessary to the chemical processes of life than is nitrogen. If the nitric acid formed by nitrification were to accumulate in the soil, it would soon become injurious to plants; for, as a rule, they cannot endure much acidity of the soil water. This condition is prevented, however, by some of the soil minerals. Review the text about minerals and learn which is especially useful in neutralizing acids. Sulphur, nitrogen and phosphorus freed from humus by oxidation thus enter the plant as constituents of sulphates, nitrates and phosphates of potassium and calcium or other metals.

When air is pretty much excluded from the soil, as where much water is present, oxidation is incomplete. In such cases organic acids, which are products of partial oxidation of other organic compounds, may be formed. What would then happen, if calcite were also present? In such cases, also, reduction may even go on. That is, carbon, unsatisfied in its affinity for oxygen, may remove this element entirely from nitrogen. The latter element, at great loss to the fertility of the soil, will then escape into the air as a free gas. All the energy expended by legume crops in obtaining it will thus be lost. This particular process, called denitrification, is due to special kinds of bacteria. Knowing that the presence of too much water and too little air is the cause, how would you treat the soil to avoid it?

Retention of Fertilizers by Soil Minerals. The minerals of the soil also take part in its chemical reactions. We have seen how they combine with products formed in the oxidation of humus. Perhaps the next most important way in which they react is in "fixing" soluble fertilizer compounds. By this is meant the rendering of soluble fertilizing elements insoluble, such as by forming precipitates with them.

Calcite and limonite react with acid phosphate when it is applied to the soil. They cause the precipitation of phosphoric acid from the soluble form as insoluble phosphates of calcium or iron. The loss of phosphorus by leaching out of the surface soil is thus prevented. At the same time, the new phosphates formed are so finely divided as to dissolve in the carbonated soil water for the use of plants.

By double decomposition potassium is taken from its salts by some of the silicon minerals and some other metal is set free in its place. The zeolites possess this power to the greatest extent. They resemble the micas in composition and are believed to have been reformed from older rocks. They contain water; and to this their reactiveness is attributed. Zeolites are abundant in the dark trap rock which forms the famous Palisades of the Hudson.

Alkali soils are a special difficulty to farmers of some regions. So much of various salts accumulates in the surface soil of these regions that they become poisonous to most plants. Alkali soils are common in the western part of the United States. The salts which they contain may have been left behind in the evaporation of undrained lakes like the Great Salt Lake. Sodium chloride, sodium sulphate and sodium carbonate are the most common salts of alkali soils. Because the sodium carbonate dissolves some of the humus and so darkens the surface of the soil, it is called "black alkali." It is more injurious to crops than the other salts. Gypsum improves "black alkali" by reacting with it to form the less poisonous sodium sulphate and calcium carbonate. The best treatment for "white alkali," so called from the white crust of sodium sulphate and other salts, is irrigation combined with drainage. This washes the salts from the soil. In dry climates it is the practice to till the soil frequently so as to check evaporation and the rise of alkali salts to the surface by capillarity. The following figures show great differences between a plant native to regions of alkali soils and some common crops.

Table VII. Greatest amounts of salts which can be present without injury to the plants named

	Sodium Carbonate	Sodium Chloride	Sodium Sulphate
Peach	700*	1,000	9,600
Wheat	1,500	1,200	15,100
Alfalfa	2,400	5,800	102,500
Salt Bush	18,600	12,500	125,600

*Values are pounds of salt in the four surface feet of soil per acre.

Analysis of the soil to determine its fertility value is carried out in the laboratory in two ways. One method, mechanical analysis, determines the proportion of particles of different sizes. The soil grains are graded from clay through silt and fine to coarse sand up to fine gravel. This division can be made by the different rates at which the larger and smaller particles sink in water. It is a measure of texture. The other method, chemical analysis, determines either the total amounts of the essential elements present or the amounts soluble in some solvent. It is well for the farmer to know the total store of plant food in his soils. That knowledge, however, does not inform him how much food his crops can get. The part which the crops can get is called "available" plant food. Water and acids of various strengths have been used to extract it from the soil. None of these agents is very satisfactory, however. They cannot be made to duplicate at one time the varied combined action of plants, bacteria and

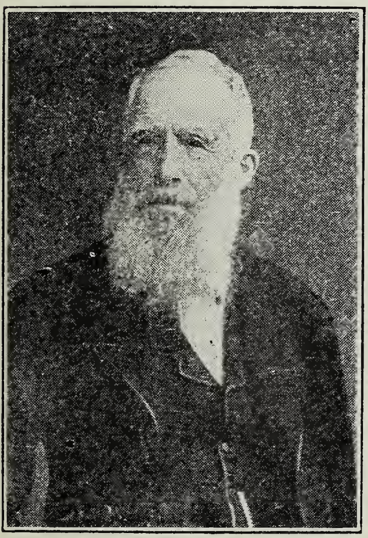


Figure 63. . John B. Lawes, 1814-1900. The founder of the Rothamsted Experiment Station near London, which he bequeathed to the people of England. His experiments are our chief source of information about the food needs of crops.

the soil solution upon the stores of plant food materials in the soil. They are useful for comparing soils with one another, but none can approach the accuracy of using the growing plant itself as a measure of availability. So we find that the study of the plant and of the soil are inseparably dependent upon each other. A fertile soil is, indeed, the necessary foundation for prosperity in agriculture and the welfare of man.

SUMMARY

In the process of cooling from a very hot gaseous state the chemical elements which formed the earth united to form water and minerals. Some of the latter have been changed in composition during past ages and some of them are very complex in chemical structure. With the coming of living things which attached themselves to the rocks the destruction of the latter and the formation of fertile soils went on rapidly. The soil is not a fixed portion of these materials, but is a state in which they are continuously being destroyed and renewed.

The formation of fertile soil requires the breaking of rocks into small particles. In past ages the glaciers did much of this work. Other forces, which are still active from season to season, have been the expansion of freezing water, stresses in the rock due to temperature changes and the grinding action of running water and sand-laden wind. The destruction of organic matter, which is of importance equal to the breaking of rocks, is chiefly due to oxidation, caused by bacteria and other living things of the soil. (The proper favoring of those forces which make the rock and organic materials useful requires no mean degree of skill in the farmer.)

Most rocks are cemented mixtures of different minerals. The greater part of these minerals is formed by silicic acid and insoluble, resistant salts which it forms with aluminium, as well as with potassium, magnesium and other basic elements essential to plants. In some of the simpler soil minerals essential acid elements are present, as sulphur in selenite and phosphorus in apatite.

Humus, present only in the surface soil, results from the partial oxidation of plant tissues, farm manure and similar organic matter. It binds the mineral particles together, aids in dissolving them for plants and supplies nitrogen to the soil. Proper warmth and airing of the soil are necessary to the greatest usefulness of humus.

The chief physical properties of the soil are its power to absorb water and heat. Fineness of the mineral particles and presence of much humus increases the absorption of water. The power of the soil to absorb heat is controlled by the amount of water present. Too much water, by absorbing heat, makes the soil cold and should be avoided by tile drainage.

The chemical properties of the soil depend upon the composition and chemical reactions of the minerals and humus. Oxidation of the humus is very important in this respect. When it is complete, useful products such as carbon dioxide, nitric acid, sulphuric acid and so on are formed. Calcite favors the process by neutralizing the acids as they are formed, thus preventing injury to the bacteria or plants. The particular process of oxidizing the nitrogen of humus is called nitrification. In poorly drained soils, lacking oxygen, organic acids and free nitrogen are produced from the humus. Other minerals than calcite take part in chemical reactions of the soil, especially with some soluble fertilizers. Certain silicates, the zeolites, combine with potassium; and calcite and limonite produce insoluble phosphates. Loss by leaching is thus prevented. Alkali soils present special injurious conditions whose only complete remedy is the combining of irrigation with drainage.

Mechanical and chemical methods for analyzing the soil are valuable, especially for comparing different soils. The growth of plants upon the soil is still the only method, however, by which fertility can be measured accurately.

QUESTIONS

1. Name soil minerals which contain the following elements: potassium, calcium, magnesium, iron, sulphur, phosphorus.
2. How is humus formed?
3. What are its important chemical and physical properties?
4. In what way does fineness promote the value of soil minerals?
5. How do water and temperature act to pulverize the minerals?
6. Which type of soil has the greatest water-holding power?
7. What is the chief cause of coldness in soils? What is the remedy?
8. What causes the oxidation of organic matter in the soil? Why is the change important?
9. What is nitrification? Denitrification?
10. What is the composition of zeolites? Why are they important in soils?
11. Why are calcite and limonite important in soils?
12. What is the cause of alkali soils? Of black alkali?
13. How can these soil troubles be treated?
14. What is the mechanical method of soil analysis? What property does it measure?
15. What is meant by the term "available" when applied to plant food of the soil?

CHAPTER VIII

FERTILIZERS

The earlier meaning of *manure* included anything which rendered the soil more productive. Even tillage was called by some a manuring of the land. A true understanding of the fundamental principles of manuring was made possible by the aid of chemistry. Justus von Liebig became the central figure in the study of this particular phase of chemistry. Other noted investigators were Lawes and Gilbert who established the Rothamsted Experiment Farm, the first step in systematic agricultural experimentation.

Classes. There are numerous kinds of manures and fertilizers some of which have several functions or uses. They may be, however, roughly divided into classes, such as (1) commercial fertilizers, (2) farm manures, (3) green manures, and (4) soil amendments. This chapter will be limited to commercial fertilizers and soil amendments.

Commercial Fertilizers. These substances are quite varied in character depending upon their source and their chemical composition. Their chief function is to add plant nutrients to the soil, though there may be other beneficial effects produced by certain fertilizers. A fertilizer may be useful on account of the presence of one or more plant nutrients. The composition and solubility of these ingredients directly affect the value of the fertilizer.

As already indicated, there are ten chemical elements which are required for plant life. Commonly only three of these are likely to be deficient in soils and must then be supplied to the plant for its proper growth. Let us now discuss the materials grouped under each of these elements.

Fertilizers Used for Their Nitrogen. Nitrogen is probably the most important constituent of fertilizers.

In the first place it is quite likely to be deficient in soils. Then its availability to crops varies greatly depending upon the kind of material which carries it. Finally, it is the most expensive ingredient of fertilizers. The nitrogen of commercial fertilizers may be in the form of a soluble inorganic salt or combined in organic matter. The inorganic compounds are readily soluble and available to plants, while the organic forms must pass through the various processes leading to nitrification before the plant can use them. It is necessary to know, therefore, the character of the compound or material which contains the nitrogen.

The principal inorganic nitrogen fertilizers are sodium nitrate, ammonium sulphate, calcium nitrate, calcium cyanamide and ammonium nitrate. Other materials are sometimes used, such as potassium nitrate. One of these, sodium nitrate, is a natural product; another, ammonium sulphate, is a by-product of the manufacture of illuminating gas; the others, calcium nitrate, calcium cyanamide and ammonium nitrate are manufactured from atmospheric nitrogen especially for use as fertilizers and for other commercial purposes. What, for example, is an important use of nitric acid? of ammonia?

Sodium Nitrate. This salt occurs in the crude condition in northern Chile. It is believed that the compound accumulated there from a combination of circumstances, the action of soil organisms through a very long period, the freedom of the region from rains, etc. The crude salt is dug from beneath an overlying layer of earth, and is purified by dissolving in water and by crystallization. As marketed, it contains about 96% sodium nitrate, equal to about 16% nitrogen, 2% water, and small amounts of impurities, such as chlorides, sulphates and insoluble matter.

Sodium nitrate is very soluble in water; in fact it readily absorbs moisture from the atmosphere. On account of this fact it is easily available in the soil and is the most active form of a nitrogenous fertilizer. It is used largely by market gardeners and wherever quick growth is desired. On meadow land and small grains it stimulates growth before nitrification makes the soil nitrogen available.

Sodium nitrate is not easily absorbed by the soil in large quantities and is easily lost in the drainage water. Would you apply this fertilizer, then, where there were no crops upon the soil? Would you advise large or small applications even if there are growing crops? The long continued use of sodium nitrate results in injury to the soil. On account of the fact that the nitrogen is used by the plant much more abundantly than the sodium, the latter accumulates in the form of sodium salts, particularly sodium carbonate. This compound chemically is a mild alkali (do you recall some of its uses?) and produces a deflocculating action, breaking down the soil particles and compacting and injuring the soil structure.

Ammonium Sulphate. This compound is a by-product in the manufacture of illuminating gas. How is it prepared? Why is the ammonia separated from the illuminating gas? Commercial ammonium sulphate contains about 20% nitrogen. It is a more concentrated nitrogenous fertilizer than sodium nitrate, having 60 to 80 pounds more nitrogen to the ton. Which of these two fertilizers would have the advantage of cheaper freight rates per pound of nitrogen supplied? It does not have as quick an effect upon crop growth as Chile saltpetre, but it is less quickly removed by drainage water, as the ammonium salts are more readily absorbed and retained by the soil. The nitrogen in the nitrate and ammonium sulphate cost about the same per pound. Which fertilizer costs the more per ton?

The long continued use of ammonium sulphate on soils affects the condition of the latter and produces results that are unfavorable for crop growth. These results are due to the fact that the ammonium radicle is utilized more rapidly than the sulphate radicle and the latter consequently accumulates in the soil, giving rise to so-called acid soils.

Nitrogen from the Air. The supply of nitrogen in the soil is limited. Though there are certain tendencies of nature to constantly restock the soil with this constituent, yet there are other tendencies for the supply to be continually depleted. The necessity for applying nitrogenous fertilizers in order to stimulate crop growth has been recognized for a long time. The amount of available nitrogen, though, is yearly becoming smaller and it will be necessary, when the supply of Chile saltpetre is exhausted, to secure another source of nitrogen for this purpose. Where is the most abundant supply of this element in nature? Where will man find the nitrogen which he can convert by some chemical process into a solid substance which in turn he can apply to the soil? After a great many years of experimentation, the last question has been answered and to-day there are on the market at least three chemical compounds containing nitrogen secured directly from the atmosphere.

Calcium cyanamide is one of the compounds referred to. It is prepared by passing nitrogen through closed retorts containing powdered calcium carbide, heated to a temperature of 1,100°C. Calcium cyanamide and free carbon are formed, the latter giving the product its characteristic black color. It is necessary for the success of the process that the nitrogen be free from oxygen before it is passed over the carbide. What chemical reaction would result if the oxygen were not removed? How may nitrogen be separated from the oxygen of the air?

Commercial calcium cyanamide is a heavy black powder with a somewhat disagreeable odor. It is now manufactured in America and can be obtained in large quantities. The name *lime-nitrogen* is commonly applied to this substance. It contains 15 to 23% nitrogen, 40 to 42% calcium, 17 to 18% carbon.

Under favorable conditions the nitrogen of the cyanamide is converted into ammonia which can be utilized by crops. Under unfavorable conditions, however, two other substances, acetylene and dicyanamide, may be formed, both of which are toxic to plants. Where does the acetylene come from? By incorporating the calcium cyanamide into the soil eight to fourteen days before the seed is planted, the possibility of this poisonous action may be overcome. The value of lime-nitrogen seems to be greatest upon heavy soils, but upon sandy soils it ranks very low.

Calcium Nitrate. This substance is made from atmospheric nitrogen in the following manner. Air is passed over electric arcs of a very high power and temperature. The nitric oxide thus formed is passed through milk of lime, giving calcium nitrate. The expense of the operation is governed almost entirely by the cost of electricity.

Calcium nitrate has a yellowish white color, is easily soluble in water, and *deliquesces*, absorbs moisture, very rapidly from the air. Are there any objections to such a property in a fertilizer? The difficulties involved in this deliquescence are overcome in two ways, first by adding an excess of lime, second by grinding the material and packing in air-tight casks. The first product, called basic calcium nitrate, contains 8.9% nitrogen, while the second product has from 11 to 13% nitrogen.

Comparing the common property of the nitrates of sodium and calcium of easily absorbing moisture, what predictions would you make concerning their availability to plants and their lack of absorption by soils?

Calcium nitrate may be spread upon the surface of the ground as it exerts no poisonous action and does not tend to form a crust as does sodium nitrate.

Both calcium nitrate and calcium cyanamide are being produced at less cost per pound than sodium nitrate laid down in the neighborhood of the factories in Europe. It seems, though, that with improved processess the cost of nitrogen in artificial products will be greatly reduced.

Fertilizers Containing Organic Nitrogen. A number of commercial products of plant and animal origin are valuable for the nitrogen they contain and are used sometimes as feeding stuffs and sometimes as fertilizers. The by-products of slaughter houses are examples of such materials. They are dried blood, dried meat, tankage, hoof meal and a few other inferior products. Of these substances, dried blood is the most readily decomposed. What effect would that have upon its availability? It produces results far more quickly than any other form of organic nitrogen. Moreover, as an animal product, it contains from 0.9 to 1.8% of phosphorus. Dried meat is not decomposed as readily, but is in fact utilized generally as feed for hogs or poultry. The resulting manure contains most of the nitrogen of the original meat so that two purposes are served in this way.

Tankage is a general mixture of refuse material from slaughter houses. It has usually been steam cooked in order to separate the fat and gelatine and render the residue more easily fermentable in the soil. It is variable in its composition, since it includes the otherwise unusable parts of the carcass, as bone, tendons, flesh, hair, etc. Concentrated tankage is obtained by evaporating the fluids from the animal matter and is the richest in nitrogen, as well as more uniform in character than the other forms of tankage. Because of the fineness of division and the physical character of the concentrated tankage, it undergoes decomposition more readily than common tankage and allows its nitrogen to be more easily utilized. Such material contains from 10% to 12% nitrogen, but very little phosphorus. The inferior grades of tankage contain from 4% to 9% nitrogen and from 1% to 5% phosphorus. Tankage varies so much that it is always sold on the basis of its composition.

Hoof meal contains a large amount of nitrogen, but the meal decomposes very slowly. Leather meal and wool and hair waste are so difficultly decomposed that they may retain their original structure for years after being placed in the soil. All materials of such character may, however, be rendered more available by treatment with sulphuric acid. Would it be of any advantage to the farmer to know whether the nitrogen of fertilizers came from high or low grade materials?

Dried blood contains from 6% to 13% of nitrogen, dried meat and hoof meal 12% to 13%, and tankage between 4% and 12%, depending upon its condition and grade.

Ground fish, fish meal, and fish tankage are excellent forms of organic nitrogen. They are by-products of the fish canning and packing industry and of oil works, such as the menhaden industry. These fish materials have a lower per cent of nitrogen than blood or meat (8%), but it is readily available, since fish readily decomposes in the soil.

Certain vegetable products as cotton seed meal, linseed meal and castor pomace are used as fertilizers, though they are more often directly used as feeding stuffs. Their fertility constituents are then available in the manure. Cottonseed meal contains 6% to 7% nitrogen, linseed meal 5½%, and castor pomace 6%. These meals decompose rather slowly in the soil on account of their oil content. They contain some phosphorus as well as nitrogen.

Fertilizers Used for Their Phosphorus. There are two main classes of phosphorus fertilizers: the mineral phosphates, and those associated with organic matter. The latter decompose more quickly in the soil than untreated mineral phosphates on account of bacterial action upon them. Some animal and vegetable products used for nitrogen also contain phosphorus. Name some that have been mentioned.

Bone phosphate is used in several forms. Raw and steamed bone, either ground or unground, and bone tankage are the more common forms; bone black and bone ash are also used after having served other purposes first. The more finely ground the bones, the more quickly they are available. Why? The steaming process also facilitates the availability of bones, inasmuch as it frees them from fat and nitrogenous matter and produces a better mechanical condition. The form of phosphorus in all these materials is the same, namely *tricalcium phosphate* $Ca_3(PO_4)_2$. All these carriers of phosphorus are slow acting and should be used for the permanent upbuilding of the soil fertility rather than as an immediate source of phosphorus.

Raw bones contain 9.5% phosphorus and 4% nitrogen; steamed bones contain 12% to 15% phosphorus and 1½% nitrogen; and bone tankage contains 3% to 4% phosphorus.

Mineral Phosphates. There are a number of natural deposits of mineral phosphates in different portions of the world, some of the most important of which are in North America. The form in which the phosphorus exists in these deposits is *tricalcium phosphate,* but a variety of substances is associated with it. South Carolina phosphate contains 11 to 12% phosphorus with but a very small amount of iron and alumina. Florida phosphates occur in the forms of soft phosphate, pebble phosphate and boulder phosphate. Soft phosphate contains 8 to 13% phosphorus. It is more easily ground than most of these rocks and is often applied to the land without being converted into a superphosphate. Tennessee phosphate contains from 13 to 15% phosphorus.

Basic slag, phosphate slag or Thomas phosphate is a by-product in the manufacture of steel from pig iron rich in phosphorus. The phosphorus is present in the form of tetracalcium phosphate, $(CaO)_4P_2O_5$. It also contains calcium, magnesium, aluminium, manganese, silicon, and sulphur. Basic slag, when ground, may be applied directly to the soil, because its phosphorus is more readily soluble than the tricalcium phosphate.

Superphosphate Fertilizers. These are prepared by treating bone and mineral phosphates with sulphuric acid, the object being to render the phosphorus of such materials more readily available to plants. Part of the calcium is replaced by hydrogen and *monocalcium phosphate* is formed. Calcium sulphate is another product along with a small amount of *dicalcium phosphate.* Some sulphuric acid is also consumed in this treatment by the impurities present in the phosphate rock. Calcium and magnesium carbonates, iron and aluminium phosphates, calcium chloride and calcium fluoride are the principal impurities. They use up more or less of the acid, depending upon their quantity, and give sulphates of calcium, magnesium, iron and aluminium. Would you regard the presence of such impurities of any importance in the manufacturing process? Why?

Monocalcium phosphate, *acid phosphate or superphosphate,* $CaH_4(PO_4)_2$ has the same value in both bone and rock material. But the tricalcium phosphate of bones is more valuable than that of rock phosphate. Bone superphosphate contains about 5% available phosphorus. Rock superphosphate varies from 5% to 8% available phosphorus, depending upon the source of the mineral.

Double superphosphates contain twice as much available phosphorus as those made in the ordinary way. Poorer grades of phosphate rock are treated with sulphuric acid and the soluble phosphoric acid and excess of sulphuric acid are separated by filtering from the mass. This solution is then used to treat phosphate rock rich in tricalcium phosphate. Double superphosphate is the most concentrated material containing available phosphorus.

Reverted Phosphoric Acid. When part of the phosphoric acid of superphosphates becomes less easily soluble, the value of the fertilizer is decreased. This change is called *reversion.* It is much more likely to occur in superphosphate made from rock phosphate than in that made from bone phosphate. It is due to reaction of an excess of tricalcium phosphate or of calcium from impurities with monocalcium phosphate to form the less soluble dicalcium phosphate.

Relative Availability of Phosphate Fertilizers. Both the superphosphates and double superphosphates contain their phosphorus in a form in which it can be taken up by the plant at once. They can be applied, therefore, either before planting or along with planting or when the crop is growing. Crude phosphates need to be applied sometime before the phosphorus is needed by crops. The phosphorus of rock materials becomes available only through the natural dissolving processes of the soil. The presence of decomposing organic matter is a great aid to this process. Reverted phosphates are believed to be quite available to plants, but not as readily so as the superphosphates.

The degree of fineness to which the material is ground makes a great difference in the availability of the less soluble phosphate fertilizers, especially in the ground rock and bone phosphates. These materials should be ground fine enough to pass through a sieve having meshes 1-50 of an inch in diameter. In this condition a large surface of the fertilizer is subject to attack by the soil solvents.

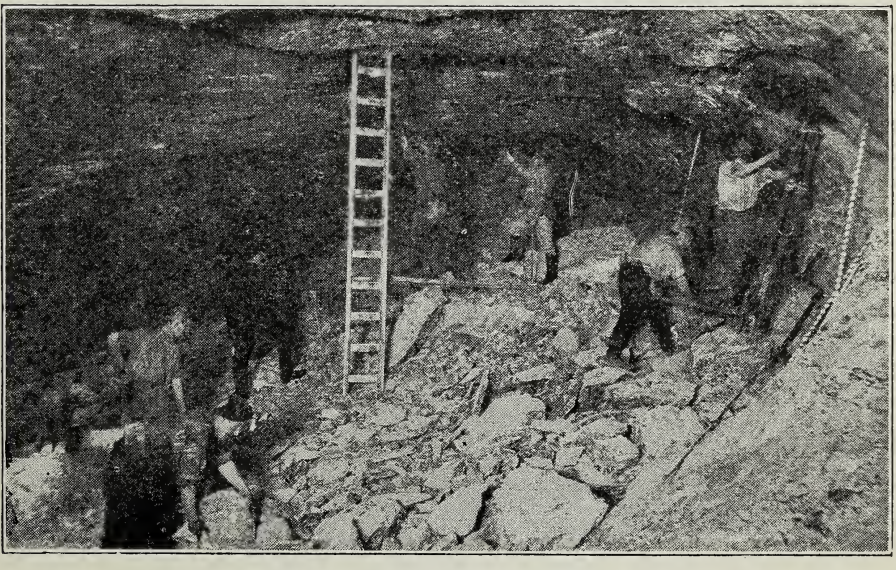


Figure 64. Mining kainite.

Fertilizers Used for Their Potassium. Potassium fertilizers are largely produced in Germany from natural sources, known as the Stassfurt salt deposits. Other deposits have been found lately in Germany and efforts are being made in the United States to locate salt deposits which contain potassium. Wood ashes were formerly used as a carrier of potassium.

Stassfurt Salts. The potash deposits at Stassfurt consist of a number of minerals. Kainite is mined in the largest quantity. Sylvinite, carnallite and kieserite are other examples of these minerals. They are usually mixtures of a number of salts as sulphates and chlorides of magnesium, potassium and sodium. The minerals may be merely crushed and powdered, in which case the fertilizer is a mixture of the chemicals named above, or the potassium salts may be separated from the other substances by solution and crystallization. The mixture of crushed minerals is a low grade potassium fertilizer, containing from 10% to 16% potassium in kainite. The purified chloride and sulphate contain respectively 41% and 42% potassium.

Potassium chloride, *muriate of potash*, KCl, has the advantage of being more diffusible in the soil and less expensive than the sulphate. But the chloride has an injurious action on certain crops, such as tobacco, sugar beets and potatoes. The sulphate is not injurious to crops. Kainite should be applied to the soil a considerable time before the crop is planted, as the chlorides present in the material may injure the vitality of the seed.

Wood Ashes. Wood ashes formerly constituted a large portion of the supply of potassium fertilizers. The potassium is present in the form of carbonate which is alkaline in its reaction and may be injurious to seeds. Unleached wood ashes contain about 4.5% potassium, 0.9% phosphorus and 21.5% calcium. Leached wood ashes contain 0.8% potassium, 0.7% phosphorus and 20.0% to

20.7% calcium. The presence of these other constituents adds to the value of the ashes.

Complete Fertilizers. There are a number of materials, as already indicated, carrying nitrogen, phosphorus and potassium, which are used as fertilizers. If a soil is known to be lacking in available nitrogen, a material which contains nitrogen may be used to supply the deficiency, similarly, in the case of phosphorus and potassium. If, on the other hand, a soil is deficient in any two or three available fertilizing constituents, then a complete fertilizer may be used. When it is considered that there is a number of materials containing nitrogen, or phosphorus, or potassium, and that the properties of these substances differ considerably; also that there are many different types of soils and crops for which the fertilizers may be used, the complexity of fertilizer practice may partly be realized. Each manufacturer of commercial fertilizers places on the market a number of brands that have some trade name. This frequently implies the usefulness of the fertilizer for some particular crop, but may not take into consideration the character of the soil upon which it may be applied. If the substances used in the fertilizer are difficultly soluble, the fertilizer is not so valuable as if composed of easily soluble substances. It is important that the purchaser should know the solubility and the percentage of each ingredient in the fertilizer.

Fertilizer Inspection. In order to protect the consumer state laws regulating the sale of fertilizers have been established. State laboratories collect and analyze samples of all fertilizers sold and make certain that the guarantee of the manufacturer is correct. Reports of such inspection are issued regularly as bulletins from the experiment stations and aid the consumer in his purchase of reliable brands of fertilizers.

Fertilizer Terms. To add to the general complexity of fertilizer practice, there is an unfortunate system of nomenclature which increases the difficulty of the farmer's understanding the labels on a fertilizer sack. Instead of the names of the elements, ammonia (NH_3) replaces nitrogen (N); phosphoric acid (P_2O_5) and bone phosphate of lime ($Ca_3(PO_4)_2$) replace phosphorus (P); and potash (K_2O) and sulphate of potash (K_2SO_4) replace potassium (K). The student will readily appreciate the fact that the quantity of these compounds is greater than the quantity of the elements alone. Therefore the amount or percentage of such constituents appearing on a fertilizer sack is greater than if only the element were indicated. What false impression would this cause?

By considering the atomic and molecular weights of these substances it is possible, however, to compute their quantitative relation. For example, the atomic weight of nitrogen is 14 and of hydrogen is 1. Therefore in the formula of ammonia (NH_3) the molecular weight is 17. The relation of nitrogen to ammonia is then 14 to 17, or as 0.8235 to 1.0. If the percentage of ammonia is given as 10.0, the percentage of nitrogen is 0.8235 times that, or 8.235. The figure 0.8235 is called a factor. Similarly, the factors of the other ratios may be shown to be (1) phosphorus is to phosphoric acid as 0.436 is to 1.0 and (2) potassium is to potash as 0.83 is to 1.0.

Values of Fertilizers. In addition to the inspection and analysis of fertilizers, several states make an estimate of their financial value. They adopt a schedule of trade values for the different forms of nitrogen, phosphorus and potassium. These values are based on the cost of the unmixed constituents and are secured by averaging the wholesale prices per ton of all the various fertilizer supplies for the six months preceding March 1, to which is added about 20% to cover manufacturers' cost, etc. The trade values for a few of the forms of plant food for the year 1914 are as follows:

	Value in cents per pound
Nitrogen as nitrates	14.0
Nitrogen in ammonium salts	13.0
Nitrogen in high grade organic material	16.5
Phosphoric acid, soluble in water	5.0
Phosphoric acid, insoluble, in fine bone	3.0
Potash, as sulphates	5.0

The commercial value of a fertilizer may be found if the percentage of each constituent, its form and availability, and the trade value of such forms are known. For example, here is a fertilizer which cost $42.00 a ton and had the following composition:

Nitrogen in sodium nitrate	4%
Phosphoric acid, soluble in water	6%
Phosphoric acid, insoluble, in fine bone	22%
Potash, as sulphate	8%

The number of pounds of each constituent per ton of fertilizer is then found to be

Nitrogen in sodium nitrate	4% of 2,000 = 80
Phosphoric acid, soluble	6% of 2,000 = 120
Phosphoric acid, insoluble	22% of 2,000 = 440
Potash, as sulphate	8% of 2,000 = 160

Applying the trade values to these several constituents,

Nitrogen as nitrates	80 × 0.14 =	$11.20
Phosphoric acid, soluble	120 × 0.05 =	6.00
Phosphoric acid, insoluble	440 × 0.03 =	13.20
Potash, as sulphate	160 × 0.05 =	8.00
	Total	$38.40

The computed value can then be compared with the commercial value. As a rule the commercial value and the trade value of high grade fertilizers more nearly coincide than those of low grade mixtures. In other words, it is a good business policy to buy high grade materials of high cost than low grade and cheap fertilizers.

Home Mixing. Several experiment stations have shown that it is possible to buy and mix fertilizers on the farm with as good results as can be obtained with mixtures that are bought. This procedure has several advantages, namely, it is claimed to be cheaper than the purchase of ready mixed fertilizers, the farmer can ascertain by field tests the best proportions of the various fertilizer constituents to use on his land, and he can know the character of the material he is using. There are the disadvantages, however, that it is not always possible to obtain the simple constituents and that it is relatively more difficult to properly blend the materials of the mixture on the farm than by the use of fertilizer machinery.

Soil Amendments. Those substances which are added to soils to increase their productive capacity by affecting the physical structure of the soil as well as its chemical and bacteriological properties are called soil amendments. The principal chemical substances used for this purpose are calcium salts, especially calcium carbonate and calcium sulphate. The former is of the greatest importance in connection with soil fertility. It not only serves to cause the granulation and flocculation of clay soils, but also to bind the particles of a sandy soil together. Limestone also neutralizes the acidity of the soil and thereby improves the conditions for soil bacteria. Again lime seems to have the effect of liberating plant food constituents which are not in a readily available form, such as phosphorus and potassium. Gypsum, calcium sulphate, was thought to have this same effect of liberating plant food, especially potassium. It is also used to neutralize black alkali, but has no effect upon soil acidity. Gypsum seems to have some influence upon the physical properties of the soil, but not as marked as limestone. The reaction upon sodium carbonate, or black alkali, is interesting in that it is the same as is used in the softening of water by the addition of washing soda.

$$CaSO_4 + Na_2CO_3 \rightarrow CaCO_3 + Na_2SO_4$$

Sodium sulphate, or white alkali, is not as toxic to plants as the black alkali.

Methods of Application. In order to secure the maximum efficiency of a fertilizer, it is necessary to apply it to the soil in such a manner that the plant food constituents are most thoroughly and uniformly distributed throughout the feeding range of the crop roots. For this purpose special machinery is available to distribute the fertilizer either in rows, beside the rows, or broadcast uniformly over the entire surface. Many drills and planters are provided with special attachments for fertilizer application, but an ordinary grain drill may serve fairly well for broadcasting the material. The rate of application varies from 200 to 600 pounds per acre, the average being about 400 pounds.

Choice of Fertilizers for Specific Soil Types. The character of the soil, in certain cases, often indicates what plant food may be lacking. Clay soils are usually well supplied with potassium, but are likely to be deficient in phosphorus. Sandy soils not only often lack potassium but phosphorus as well. The same lack is true of many gravelly soils. Peaty soils are generally rich in nitrogen, but are deficient in potassium and phosphorus. The nitrogen compounds, however, are not quickly available. In the numerous mixed types of soils, and most soils are of this character, these general statements do not apply.

Choice of Fertilizers for Specific Crops. Among the differences in the individual characteristics of crops the feeding power of the crop affects the choice of the fertilizer. Agricultural plants may be conveniently divided into several different classes, the members of which, while differing in many ways, have in common certain resemblances that are of importance in this connection.

(1) *Cereal crops* are comparatively shallow rooted and occupy the upper layer of soil extensively before the end of the season. Consequently fertilizers for such crops are most effectively applied in the upper layer of soil, especially if they are very soluble. Barley, oats, rye and wheat

need a large proportion of their nitrogen in the early part of the growing season. Nitrate nitrogen is usually found most beneficial, because there is a lack of this constituent until after the soil becomes warm. Corn, on the other hand, which makes its best growth after the other cereals have matured, can utilize organic forms of nitrogen. The nitrification of such materials is most active by the time the corn crop makes its greatest demands. All cereals are generally benefited by the application of acid phosphate. Barley, especially, needs such a fertilizer, owing to its comparatively shallow root system.

(2) *Leguminous crops* are vigorous feeders and are aided greatly by their long roots which go deep down into the soil. In spite of their ability to derive nitrogen from the air, their chief characteristic property, small applications of available nitrogen are beneficial upon poor soils, particularly in the case of alfalfa. Calcium, potassium and phosphorus are very effective with legumes upon most soils.

(3) *Grass crops* are generally shallow rooted and consequently have a narrow feeding range. Permanent meadows and pastures are greatly benefitted by fertilizers, nitrogen in soluble forms being especially useful, because the growth of the stems and leaves is largely dependent upon this element; but nitrification is very slow in soil that has been occupied by a crop longer than one year.

(4) *Orchard crops* collect their food both from a considerable area and depth of soil. They need a continuous supply of plant food in moderate amounts and in fairly soluble form. Care should be used, however, not to fertilize in such a manner as to make rapid growth of new wood or to prolong the growth till too late in the fall.

(5) *Root crops* obtain their food from a comparatively limited area. Fertilizers must be supplied them in fairly soluble forms. Turnips respond to phosphorus and carrots and beets to nitrogen compounds.

(6) The chief purpose in growing *garden crops*, in most cases, is the production of leaves and stalks of a tender succulent character. This quality depends upon rapidity of growth and, therefore, an abundance of soluble nitrogen is essential. Enough available phosphorus and potassium must be furnished to allow the nitrogen to accomplish its maximum work. Farm manure is used for such crops and often in large quantity.

In general it may be said that for crops whose root systems extend sideways in every direction it is preferable to broadcast the fertilizer and harrow it into the ground before planting. In the case of crops whose root systems extend downward it is advisable to distribute the added plant food in or near the rows or hills. Concentrated fertilizers, however, may injure seeds and young plants; hence such substances must be kept from coming into direct contact with the seedling.

Those plant food materials which are easily soluble, diffuse through the soil readily, and are not well retained by the soil should be applied only when the crop is ready to use them. Nitrogen in the form of nitrates is especially liable to loss. Fertilizers which do not dissolve readily should be applied early in the season and worked into the soil in order to be decomposed and made available for the crop.

Systems of Fertilization. There are many factors which modify the effect of fertilizers, such as the soil, the crop and climatic conditions. It is difficult, therefore, to prescribe general rules for applying these plant food constituents. Farmers should study their own conditions, try various combinations, and use the materials that give the most profitable results under their conditions. After ascertaining this necessary information they should then adopt a systematic method of fertilization. It must be remembered, moreover, that this system should include a rotation of crops, the liberal use of farm or green manure and all other aids to better farming. Some of the more common systems of fertilization are given below.

(1) The system based on the influence of a single element. It is assumed that plants can be divided into three groups, one group being most benefited by nitrogen, another by phosphorus, and another by potassium. Nitrogen is said to be the ruling element for small grains, meadow grass and beet crops. Phosphorus is the important element for corn, sorghums and turnip crops. Potassium is dominant for the legumes, flax and potatoes. If the soil is fertile, the dominant element is supplied to force a maximum growth of the crop. If the soil is not fertile, liberal portions of the dominant element are supplemented by moderate additions of the other plant foods.

(2) The system based on the necessity of an abundant supply of the fertilitizer elements. This method is useful in building up a very poor soil when accompanied by a rotation and the application of manure. Potassium and phosphorus are relatively cheap and easily retained by the soil, but nitrogen is expensive and easily lost. Hence a reasonable excess of potassium and phosphorus is applied to more than satisfy the maximum needs of any crop and then the nitrogen is applied in an available form and at such times as will insure the minimum loss of the element and the maximum growth of the plant. The phosphorus and potassium may be supplied in their cheapest forms.

(3) The system based on the amount of plant food taken up by the crop. This method requires that different plants be fertilized in the proportion in which chemical analysis shows the three elements, nitrogen, phosphorus and potassium, to exist in the plant. If an abundance of plant food is furnished, the system may be profitable; but it is not so for ordinary farm crops. It does not consider the facts that plants vary in their power of absorbing different ele-

ments and that the period of growth exercises some effect upon the plant's ability to acquire food.

(4) The system based on the money crop in a rotation. The most profitable crop in the rotation is supplied with an abundance of the fertilizer in order to insure continuous feeding and maximum production. The remaining crops or those immediately succeeding in the rotation are nourished by the fertilizer residues, with further small applications, if necessary. This method has the advantage of being the most practical of all, that is, the most certain of giving profitable returns. The other methods are as yet subject to uncertain returns, due to the changing effects of environment and unknown properties of the different plants.

SUMMARY

Fertilizers are used for the plant food constituents, nitrogen, phosphorus and potassium, which they contain. There are many different kinds of carriers of these substances and they vary in solubility, availability and effect upon crops and soils. Fertilizers are mined from deposits, they are manufactured from the air, and they are derived as by-products of certain industries like those of packing houses and chemical works. The raw materials of fertilizers may be treated to make them more available to crops. Sulphuric acid is especially useful for this purpose.

The use of fertilizers is not a simple matter. The character of the material itself, of the crop and of the soil must all be taken into consideration. In order to aid the consumer a rigid fertilizer inspection is enforced by law in the various states. This ensures the consumer's securing goods up to the guarantee and within a reasonable amount of the actual commercial value of the constituents. It is possible for the farmer to study his own soil needs and mix his own fertilizer.

Other substances are applied to soils, but not for the purpose of adding plant food. They act as stimulants or amendments. The most notable example is calcium carbonate which improves the physical tilth of soils, betters the bacteriological conditions and helps liberate plant food.

QUESTIONS

1. Name the elements which are necessary for plant and animal life.

2. What substances, that are necessary for plant life, are liable to be absent from soils and how may they be supplied?

3. Name ten common ingredients of commercial fertilizers, stating their source and the constituent of fertilizing value.

4. Which class of fertilizers do you consider of the greatest importance and why?

5. Why is it necessary to know the analysis and guarantee of a commercial fertilizer?

6. As a general rule is it advisable to use low grade fertilizers?

7. How does the use of calcium carbonate differ from that of a nitrogenous or phosphatic fertilizer?

8. What are some of the factors that affect the availability of fertilizers?

9. What are some of the principal factors which must be considered in the application of fertilizers?

10. Is it necessary to use other methods along with fertilization in the effort to upbuild the soil fertility? State reasons.

11. Would you advise (a) adding calcium sulphate to overcome the acidity of a soil; (b) adding a potassium fertilizer to a clay soil; (c) a phosphorus fertilizer to a soil to be cropped to small grains? State reasons.

12. What in your opinion is the chief point to keep in mind for maintaining the fertility of the soil of your farm? Tell why you think so and the method of meeting this problem.

CHAPTER IX

FARM MANURE

Fertilizing Importance of Manure. When farmers know the composition and properties of manure which determine its great value to crops, such wasteful methods of handling it as are shown in Figure 65 will be replaced by efforts to obtain from this material the greatest possible value. Our present purpose is to learn the chemical principles by which the conservation of its properties may be accomplished.

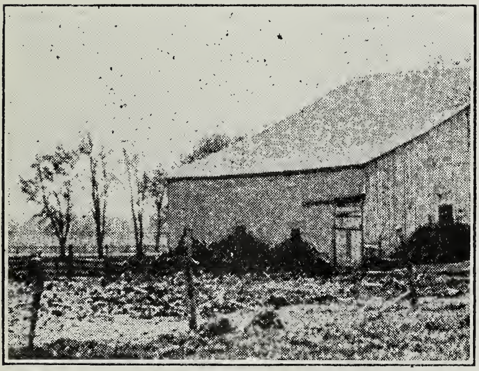


Figure 65. Loss of value in manure by leaching. The water running from this large roof washes the best of the plant food from the manure.

As we have previously learned in our study of the plant, certain elements essential to its growth are obtained from the soil. Is it not quite natural to question whether the soil can continue to supply these elements and support crops indefinitely? It was believed by some early agricultural scientists that tillage alone was sufficient to maintain the crop-producing power of the soil; but we know now, that, among other things, the supply of plant food must be kept up. This fact is the basis for the use of commercial fertilizers about which we have learned already. Some of these fertilizers, you will recall, act directly by increasing the supply of plant food, while others act indirectly in various ways, such as favoring the growth of helpful bacteria. Farm manure is the most generally useful and popular fertilizer, because it combines most of the valuable properties of commercial fertilizers. Perhaps the reasons for the superior value of farm manure as a fertilizer will become clearer, if we consider its source.

Source of Farm Manure. The food eaten by farm animals is a mixture of plants and plant products. It contains essential elements in the proportions in which they are taken from the soil by plants. What is nature's method for returning these elements from the plant to the soil on wild, virgin land? After the action of the digestive juices they are present in farm manure as products of partial decay. In the cycle of plant food from the air and the soil through the plant and animal and back to its sources they are at the early stages of the return. Processes of fermentation and decay tend to return them rapidly from the manure to their original sources in the air and soil. They are, one may say, in a very active and useful state which they have reached only by complex and gradual chemical changes. To permit them by carelessness to become free again would be a serious waste of chemical energy. To allow their valuable compounds in the manure to be lost would be an extravagant waste of plant food.

In our study of fertilizers we have learned that the essential elements of greatest practical importance in plant growth are nitrogen, phosphorus, and potassium. As described in the chapter on the plant, they are present in both organic and inorganic compounds. By the processes of digestion, which will be described in the next chapter, these compounds are partly changed to soluble products. The undigested portion of the food is excreted as solid matter, or dung. Most of the phosphorus, which becomes waste material after use, is also excreted in the compounds of the dung. On the other hand, the waste potassium and nitrogen are excreted by way of the kidneys and bladder in the urine. The potassium is excreted as the base of various inorganic salts, while the nitrogen is contained in organic compounds derived from the protein and closely related to ammonia. You will see, then, that the manure consists of two distinct parts: (1) The liquid portion, which contains plant food readily available for crops; and (2) the solid portion, which contains compounds from which plant food is liberated only by chemical changes of decay.

Farm manure bears to farming the relation which by-products bear to many commercial industries. A by-product is a substance obtained as a side issue from the main products, such as cottonseed oil from the cotton industry. The profits and success of many manufacturing operations depend upon the marketing of their by-products. For this reason, neglect of farm manure may cause failure, where prudent use of it would insure successful farming.

Amount of Manure Product. If we note the amount of total excrement produced by a single animal, we shall find it small for some animals. A hen, for example, produces only about two tenths of a pound per day, and a sheep five pounds. The cow, however, produces the considerable amount of about seventy pounds. When we take into account the accumulation of the manure from day to day, the amounts become surprisingly large. Thus, for a period of a year, the hen produces about seventy-five pounds, the sheep nearly a ton, and the cow fourteen tons; so you see that the manure produced on a farm of moderate size and supporting, let us say, twenty cows and the usual amount of other live stock, amounts to several hundred tons yearly. It will be interesting to calculate the amount for your own farm per year, using ten and fifty pounds for the daily production of the pig and horse respectively. The total yearly production of the United States is enormous. From the latest census returns from all classes of farm animals, it has been estimated as over one billion tons. At the standard market prices, the plant food of a ton of mixed manure is worth $2.00; hence the value of the yearly production of our country must be over two billion dollars. As we shall see later, one fourth of this value, and perhaps much more, may be lost by carelessness. Should not the farmer husband this valuable resource?

The amount of manure produced depends upon the amount of food which is fed. One can calculate roughly the amount of manure produced from a given ration. In the first place, one must compute the amount of dry matter fed. It is necessary to regard the dry matter, because the water present in the feeds is not changed in quantity by digestion, while the dry matter is. Now, one half of the dry matter on the average, is excreted as dry matter of the manure. The other half is either used in building the body tissue or excreted as gases and water. This one half of the dry ration will be increased by one half of its own weight added as dry matter in bedding. Thus, the dry matter of the manure is about three fourths of that in the ration. Now the average amount of water in mixed farm manure is 75 per cent. Putting it in another way, the fresh manure weighs four times as much as the dry matter which it contains. Therefore, if this dry matter is three fourths of the dry matter of the ration, as just stated the fresh manure will weigh four times three fourths of the dry matter fed. Hence, the fresh manure will weigh three times as much as the dry ration. Let us take an example of this calculation. A ration contains 10 pounds of clover hay and 5 pounds of wheat bran. The clover hay contains 15 per cent of water and the bran, 12 per cent. Therefore, the ration contains 8.5 pounds of dry clover and 4.4 pounds of dry bran, a total of 12.9 pounds of dry matter. Three fourths of this value, which is the sum of the dry matter excreted and the dry matter of bedding, is 9.7 pounds. The fresh manure will weigh four times this amount, or 38.8 pounds. Can you not find out the kind and amount of rations fed at home or on some neighbor's farm and calculate the amount of manure it should produce? You may need to consult a larger textbook for the percentage of water in some feeding stuffs.

The value of fresh manure depends chiefly upon the kind of feeding stuffs which are fed. Like any other product, it can be of no higher quality than the materials from which it is made. Farm manure is either rich or poor, dependent on whether the food eaten by the animals is rich or poor in the essential elements. This is especially true of nitrogen, as this is the most important and the most expensive of the essential elements. Thus, a ration containing clover hay, which contains 2.1 per cent of nitrogen, will produce richer manure than one containing timothy hay, which contains only 1.3 per cent of nitrogen. You can see from this that it is possible to increase the value of the manure by raising and feeding leguminous crops. What practically inexhaustible storehouse have we already learned is the source of the nitrogen obtained by these crops? Unfortunately, there is no such source available for either phosphorus or potassium. There is no other reservoir than the soil itself from which these elements can be obtained without cost. In order to keep the soil fertile, either the amounts removed by crops must be returned to the soil without loss or they must be replaced by purchase from outside the farm. Potassium can be obtained as a constituent of commercial fertilizers. Most types of soil, however, contain large amounts of it; so that it is not always necessary to buy it. Fortunately, phosphorus, the most frequently exhausted of the essential elements, can be recovered in certain by-products of crops. This element is especially important in grain formation and accumulates in many seeds. In wheat and rice, which form a large proportion of the common grain crops, it is present chiefly in the outer husks, which form the bran. Over three fourths of the total phosphorus of the wheat grain is removed with the bran. It is thus possible for the farmer to profit in fertilizing by purchasing wheat bran to offset feeding stuffs raised on his farm. For example, with corn at 70 cents per bushel and wheat bran at $28.00 per ton, one could purchase 0.9 ton of bran with the receipts from one ton, or 35.7 bushels of corn. The exchange would result in a gain of over 16 pounds of phosphorus, to say nothing of large gains of nitrogen and potassium. With the market values of nitrogen, potassium and phosphorus at 15 cents, 6 cents, and 11 cents per pound, respectively, the gain of fertility by the transaction would be worth over $4.50. It will be worth while to calculate the gain by this exchange at present prices, also the gain by the exchange of other crops than corn for the wheat bran. If the tables which you consult give the percentage of phosphoric acid (P_2O_5) in feeding stuffs, multiply it by 0.44 to convert to phosphorus value. Multiply the percentage of potash (K_2O) by 0.83 to convert it to its potassium equivalent.

Manurial Value of Feeding Stuffs. While making these computations on the fertility value of feeding stuffs we must remember that not all this plant food is recovered in the manure. The animal needs some of the elements for his own growth and work. The greatest needs are those of the growing animal and the mother producing milk. During the first year of their lives, cattle use about one fifth of the nitrogen and phosphorus of their food. The nitrogen is required for making muscle and the phosphorus for building bone. A cow in full milk flow uses about the same proportion of these elements in producing milk. A mature working horse, on the other hand, uses only small amounts of these elements to repair the waste of his tissues; and the mature, fattening animal retains almost no fertility, because he is doing nothing but constructing fat, and fat contains no nitrogen, phosphorus or potassium. It is generally considered that the average amount of fertility in feeding stuffs returned in the manure by all kinds of farm animals is 80 per cent of the total. This amount is called the manurial value, in distinction from the fertility value of feeding stuffs. The latter is the full value of the plant food; the former of what is excreted in the manure.

Manure of Different Animals. If we compare the composition of the fresh, mixed excrement of different animals, we shall find great differences. Sheep manure, for example, contains about twice as much nitrogen, and one half more phosphorus and potassium than cow manure. This apparently great difference is due chiefly to the different amounts of water in the fresh manure. Exclusive of the bedding, cow manure contains about 85 per cent of water, horse manure 70 per cent, sheep manure 60 per cent, and hen manure only 55 per cent. So you see that from any one feeding stuff the sheep or hen will produce a much more concentrated and hence richer manure than the cow. When the percentages of the essential elements are calculated upon the dry matter, the differences are far less. The chief difference is that sheep and hen manures are about one fourth and one third richer in nitrogen, respectively, than the more common manures. This is not due to any peculiar power of the animal, but to the nature of its food, and the uses to which it is put.

On the farm one deals with manure containing litter. We ought, therefore, to study the value of this product, rather than of the freshly dropped excrement. Fresh cow manure with bedding contains on the average 0.5, 0.1, and 0.4 per cent of nitrogen, phosphorus and potassium. You will get the value of these figures, if you will calculate them to pounds per ton of manure. Mixed farm manure contains about one fourth more nitrogen and potassium.

Urine Saved by Litter. From one half to two thirds of the nitrogen and potassium are excreted in the urine.

Therefore, just that part of the manure which is most perishable contains at least one half of its fertilizing value. Is not the great value of the urine quite clear?

This important part of the manure can be saved best by keeping the animals on tight floors and using bedding liberally. Dry peat moss is an excellent absorbent for use as bedding. It is quite as absorbent of liquids as a sponge. Straw, leaves and other common bedding materials absorb much more water when finely divided than when in coarse condition. For this reason it pays to cut straw into short lengths for bedding. When precautions have been taken to save the urine, it should be remembered that the manure is a perishable product. Like other products of this sort, it should be gotten to the consumer as soon as possible. It should be hauled to the field and spread daily as it is produced. In this way, there is the least loss of fertility and the greatest return in crops. Such results repay many fold the original cost of a manure spreader.

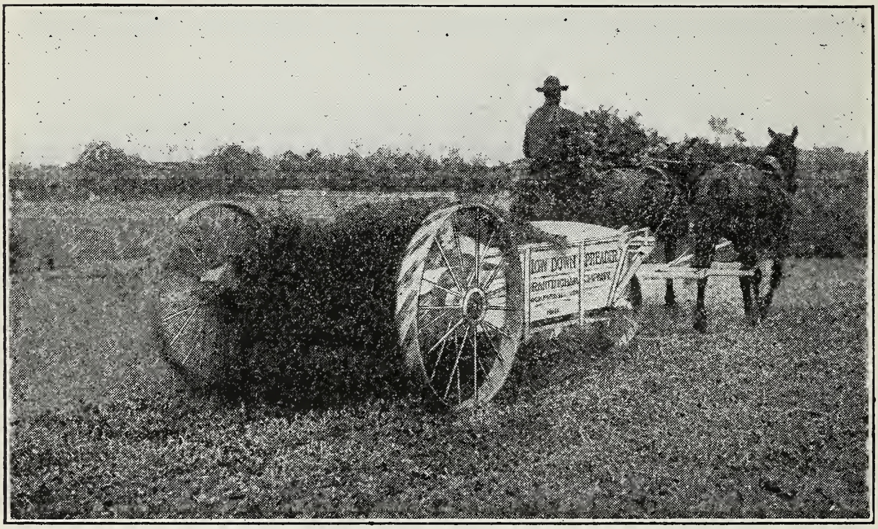


Figure 66. Manure Spreader. After the liquid part has been absorbed with bedding and litter the manure should be spread upon the land as soon as possible.

Losses in Stored Manure. When not spread directly, manure is liable to serious loss of value in two ways. In the first place, when it is rather dry and loose, as is horse manure, it is vigorously attacked by bacteria. The changes which go on are spoken of collectively as "fermentation." They are due to chemical reaction set up by enzyme-secreted by the bacteria. Two reactions proceed rapidly.

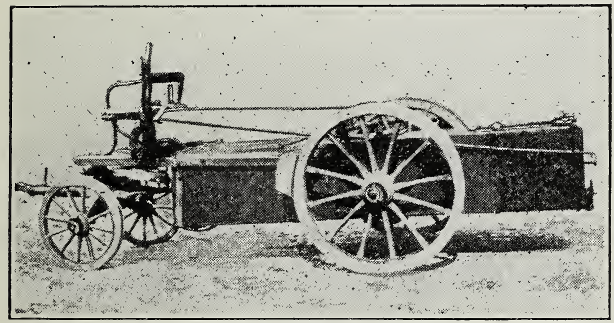


Figure 67. A cart used in Switzerland for taking liquid manure to the field.

First: oxidation, favored by the free supplying of air, destroys much of the organic matter. In what compounds will carbon and hydrogen be lost? Nitrogen will be lost as a constituent of ammonia NH_3. This process generates much heat, so that the temperature of the interior of a pile of horse manure may reach even 80°C.

Second: hydrolysis causes rapid loss of ammonia from fermenting manure. This is the kind of chemical change in which water is caused to combine with other compounds and to produce new and simpler compounds. The greatest loss is due to the union of water with urea, an important nitrogenous compound of the urine. Urea is an amide. By combining with water in the proportion of one part to two parts, respectively, it yields ammonium carbonate. This salt, as you can easily prove by smelling a lump of it, decomposes at ordinary room temperature. At the higher temperatures of the fermenting manure, it decomposes rapidly into ammonia, carbon dioxide and water. Have you not noticed the peculiar odor prevalent about horse stables in warm weather? This odor sometimes becomes fairly stifling when one forks the manure pile open. It is due to escaping ammonia. One fourth to three fourths of the valuable nitrogen of the manure may be lost in this manner.

A second serious loss occurs when manure is exposed to the rain. Where the rain falls on shallow, loose piles it washes or leaches the soluble constituents from the maure. Thus, while only nitrogen is lost by fermentation, leaching removes potassium and phosphorus also. Worst of all, it removes just those compounds which are most soluble and available for use by the crops. The residue from leaching, even by short rains, has but one half or less of the crop-producing power of unleached manure. Knowing these facts, one can realize the great value of the dark liquid often allowed to ooze away from the manure piles.

Spreading the Manure. The statements just made emphasize the importance of spreading the fresh manure directly upon the land. To leave the manure in piles in the field is nearly as wasteful as to allow it to accumulate at the barnyard. In this way, the plant food leaches into spots and most of the field fails to receive much of the benefit from manuring. Of course, one should avoid spreading the manure on steep slopes without promptly working it into the soil, as it is very likely to be washed away by rain.

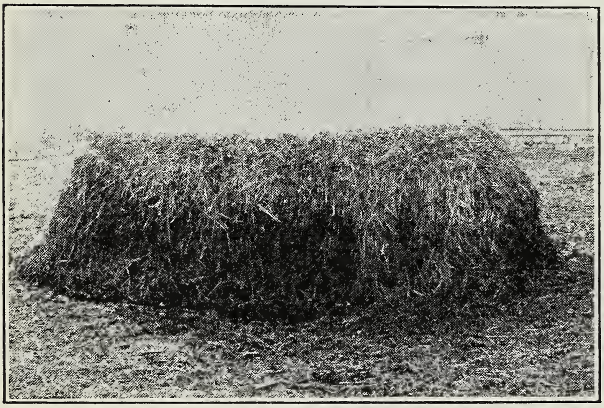


Figure 68. A properly made manure pile. It should be built high with nearly vertical sides and a depressed center.

The Manure Pile. When the manure must be kept until such times as it can be hauled to the fields, it should be piled with care. The pile should be made round with nearly vertical sides and dished at the top, as shown in Figure 68. Such a shape throws the rainfall into the center of the pile and prevents loss by leaching. Compacting the pile by treading as the manure is added reduces the air spaces and checks fermentation. Mixing the "hot horse manure" with the "cold cow manure" also reduces fermentation. The presence of a large amount of water is both unfavorable to the oxidizing bacteria, and also absorbs much heat, keeping the mass cold. Addition of water to the pile, by rain or otherwise, has the same effect. Such treatment does not entirely prevent the loss of fertility, as chemical changes are produced by the action of bacteria which thrive without oxygen. Yet the loss of nitrogen can be reduced to only one tenth of the total, whereas three fourths is often lost from poorly kept manure.

Absorbents and Preservatives. Sometimes the farmer tries to "lock the stable after the horse is stolen" by preventing the loss of ammonia set free by fermentation. This is done by sprinkling the manure with materials which retain the ammonia. These materials act either by absorbing ammonia physically or by reacting with it chemically. Dry peat and muck are good for the purpose, as they absorb large volumes of gases mechanically, just as does charcoal. The use of much of these materials in piled manure must be avoided, as they dry the manure and increase fermentation. Among the chemical preservatives, gypsum or land plaster has been commonly used. Its action depends on the fact that calcium sulphate reacts with ammonium carbonate to form calcium carbonate and ammonium sulphate. In contrast to ammonium carbonate the sulphate is not volatile and subject to loss. The process is not efficient, however, as it requires a large excess of gypsum to produce the change. Any acid material, such as acid phosphate fertilizer, will combine with ammonia. You will see that this reaction is of a much simpler kind than in the case of gypsum. These materials should be added to the manure as it is taken from the stable, for they are injurious to the feet of animals. Contrary to a common belief, "floats" or finely ground rock phosphate has no power to retain ammonia. The practice of adding either ashes or lime to manure in the barn as a "sweetener" is a very serious error. These materials should never be added to the manure, excepting when the latter is to be worked into the soil immediately. They are strong alkalies which displace ammonia from its compounds and set it free.

Increasing the Value of Manure. The farmer should aim to increase the value of his manure. As already shown, this can be done by the purchase of certain feeding stuffs. On farms which do not consume wheat bran and similar commercial feeding stuffs certain commercial fertilizing materials may be purchased for reinforcing the manure. The most common of these for supplying phosphorus are rock phosphate and acid phosphate. They are usually added at the rate of forty pounds per ton of manure, sprinkled over successive layers of manure as the spreader is loaded. Formerly it was believed that carbonic acid and other organic acids formed in the fermenting manure produced soluble compounds of phos-

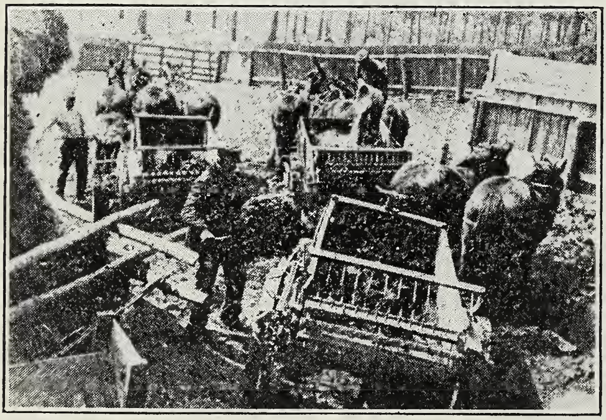


Figure 69. Mixing phosphorus and potassium fertilizers with the manure to increase its effect.

phorus from the insoluble rock phosphate. Now we know that this change does not occur in the manure pile, but in the soil. Many years of study at the Ohio Experiment Station have shown that the net returns from using acid phosphate are greater than those from rock phosphate. When the soil needs potassium, it is best to reinforce the manure with one of the high-grade potassium salts about which we learned in the chapter on fertilizers.

Use of Manure. Proper use of manure requires attention to certain scientific principles. Two important effects produced by it should be kept in mind: (1) it increases the supply of plant food; and (2) it increases the supply of humus. In order to produce either of these effects it must decay freely. If conditions do not favor its decay, uncommon compounds, poisonous to plants, may be produced. What is the chief chemical change which causes the decaying of manure, either in loose piles or when mixed with the soil? Would you expect oxidation to proceed favorably in manure buried a foot beneath the surface of the soil? Favorable oxidation of the material is best favored by only moderate applications. Eight tons per acre is a good amount to use, applying it to the tilled crop of the crop rotation. On heavy clay soils which exclude the air it should not be plowed deeper than four inches, but upon sandy soils it may be covered deeper. Can you see any reason why shallow covering of the manure and tilling of the soil have a favorable effect on the decomposition of the manure? A further reason for desiring the favorable oxidation of the manure is that it warms the soil. Manured soils are always 1° to 2°C. warmer than unmanured soils in the summer season, when bacteria are destroying the organic matter.

Rotten manure is better than fresh manure for some purposes, especially for light, sandy soils, whose unfavorable porous conditions would be increased by coarse, fresh manure; and for some uses in the greenhouse. The fresh and rotted manure are equally efficient, ton for ton; but it takes two tons of the former to make a ton of the latter; so the rotting process involves much loss. The process is carried out by composting or packing in a compact heap. Waste plant and animal matter may be added and soil is mixed into the heap. The pile is forked over occasionally and enough water added to promote oxidation. There is unavoidable loss of nitrogen in the process. Such treatment has the favorable effect, however, of killing weed seeds.

Excessive manuring sometimes causes lodging of grain crops such as oats. This is due to the production of an excess of nitrates, which produce a heavy growth of foliage. The heavy shade so weakens the stems that they break in the stress of a beating rain. A few tilled crops profit by heavy manuring. Fourteen tons per acre is a favorable application for the heavy-feeding mangel. It is good practice to spread manure on grass sod in the fall. In this way the period of nitrification is lengthened without loss of nitrates by leaching, as the growing crop assimilates them.

The effects of manure are quite different from those of commercial fertilizers. While the latter must be used continuously, the former produces favorable effects which increase the yield of crops for many years after its use.

The place of manure in keeping up the fertility of the soil has been studied for many years at the Ohio Experiment Station. It is the practice of many farm tenants to omit the use of any sort of fertilizer for fear that others will profit from their investments. The Ohio experiments show that this is the poorest sort of management. On a 160 acre farm with soil in rundown condition, an unmanured three-course rotation of corn, wheat and clover will net the farmer about $400.00. The application of eight tons of manure per acre to his corn will give a net profit of $1200.00. Still further, the use of acid phosphate with the manure will increase the profit to $1,800.00. Can any more striking evidence be needed to show the value of manure and the importance of supplementing it with commercial fertilizers? The purchase of ten tons of wheat bran yearly on such a farm will replace the phosphorus and potassium sold in its products. Indeed, a well-managed stock or dairy farm actually increases in fertility.

Green manuring is the process of increasing soil humus and available plant food by ploughing green crops directly back into the soil. Sometimes grains or grasses are grown in the fall after tilled crops and treated in this way. So used, they save nitrates from leaching and are called "catch crops." Clover, soy beans and other legumes are far better green manures than the common grasses, because they enrich the soil in nitrogen. A better common practice than green-manuring, however, is to feed these crops and carefully use the manure. In this way, they serve double usefulness.

Sewage. Human excrement is a fertilizing material whose loss forms one of the extravagant features of civilization. With the dry, earth closet, still common to country homes and villages, it is possible to return the plant food of this material to the soil. In cities, however, its accumulation becomes both a nuisance and a menace to health. This condition led to the present method of flushing excreta away with a large volume of water. Attempts have been made both to evaporate the water from the greatly diluted sewage and to precipate the suspended matter. None of these methods have yet proved practical. Some cities have experimented with filter beds of sandy soil upon which truck crops can be grown. Even this has not been found feasible for general use.

Our present wasteful practice is a great contrast to the methods of the Chinese and Japanese for saving human excrement. Figure 70 shows how extensive is the business of saving this material in a great city of China. Such a method is possible, of course, only in countries where labor

Figure 70. Collecting human manure from the city of Shanghai, China. From King's "Farmers of Forty Centuries," by permission of Mrs. F. H. King.

is cheap and the problem of growing food plants is acute. With continued increase of population in our country there must come, eventually, a shortage of commercial fertilizers and farm manure. Such a condition will necessitate the invention of practical methods for saving the enormous quantity of plant food now lost in sewage.

SUMMARY

Farm manure is a stage in the cycle of elements from the air and soil through plants and animals. That portion of essential elements contained in the liquid part of the manure is in an available and very valuable form, and should be saved by liberal use of bedding.

The amount of manure depends upon the amount of feeding stuffs fed. Its composition and value, when fresh, depend upon the composition of the feeding stuffs. After the requirements of growth and milk production are satisfied, animals excrete about four fifths of the essential elements of the feeding stuffs. By selecting certain feeding stuffs the farmer can increase the value of his manure.

Some manures are much drier than others and ferment rapidly, on account of bacterial action. Fermentation causes much loss of nitrogen from the liquid portion. The latter is also subject to heavy loss by leaching due to rain. To avoid these losses, manure should be spread on the land as fast as it is produced. When it can not be thus spread the wet and dry manures should be mixed in a compact pile. Commercial fertilizers can be mixed with it to increase its value.

In order that oxidation, by which manure is made useful, may proceed freely the material should be applied to tilled crops and not covered deeply. When so used it produces lasting effects. Its use in a three-crop rotation will triple the farmer's net profits.

Green manuring, or ploughing crops under for fertilizer, is a valuable practice where the crops are legumes. It is a less desirable practice than the combination of feeding the crops with saving of the manure.

In contrast to the careful use of human excrement in Oriental countries, our city sewage systems cause enormous losses of plant food. Increasing population may cause this waste to become a serious problem pressing chemists and engineers for solution.

QUESTIONS

1. Why is farm manure the most generally useful fertilizer?
2. Which is the more valuable per pound, dung or urine? Why?
3. What is the approximate value of the farm manure produced annually in our country?
4. How can amount of manure be computed from the ration fed?
5. Upon what factor does the value of fresh manure chiefly depend?
6. How can one increase the amount of nitrogen in the manure? Of phosphorus?
7. Does all the plant food of the ration reach the manure? Why?
8. What is the manurial value of a feeding stuff?
9. Why is loss of the urine wasteful? How can it be avoided?
10. What two serious losses may occur from piled manure? How can they be reduced?
11. How would you proceed to reinforce the manure with either phosphorus or potassium?
12. What are the objections to ploughing manure in deeply?
13. For what purposes is rotten manure preferable to fresh manure?
14. Why should heavy applications of manure be avoided with grain crops?
15. What was the difference in income from no manure and from manure with acid phosphate in the Ohio experiments?
16. What is the purpose of green manuring "catch crops"?
17. Would you advise green manuring clover on a stock farm? Why?
18. What objection would you raise to the present method of disposal of city sewage?

CHAPTER X

THE ANIMAL AND ITS PRODUCTS

The Animal Body a Factory. Can you think of your pet dog, with all his intelligence and devotion, as a machine? Perhaps you will find it easier to think in this way of your favorite cow, producing nutritious milk. She seems to put out a definite product, much after the manner of a machine or a factory. In reality, the live bodies of all animals are machines. Indeed, they are even factories, requiring only foods as raw materials and fuel to turn out each its particular product.

The work of various animals, whether it be the swift movements of the winning race-horse or the butter-fat production of the champion dairy cow, is done at the expense of energy locked up in compounds of their feeding stuffs. Their products also, whether they be the flesh of prize fat steers or the eggs of prolific hens, are made by reconstructive chemical processes from compounds of their feeding stuffs. Thus we see that, in a broad sense, the body of a living animal is a sort of self-operating, self-repairing factory. In addition to supplying raw material for making the products of this factory, food supplies it, as we shall see later, with power and heat resulting from oxidation.

The place of the animal in agriculture, then, closely resembles that of a machine or factory in other industries. From the compounds of the plant as raw material it produces power and special finished products for the use of man. Some of these products we shall study as cloth fibers, others as food stuffs. Let us now inquire further into the nature and mechanism of this living machine.

Chief Parts of the Body. In general, the animal body may be considered in four chief parts. These are: the skeleton, the vital organs, the muscles, and the skin. The actions of all these parts are harmonized by the nerves. Their chemical processes are linked together through the blood and its circulation.

The bony skeleton supports the body, forms leverage for the muscles and protects the vital organs. Bones consist of a spongy mold of protein compounds, chiefly ossein, filled with calcium phosphate and small amounts of other salts. Magnesium, fluorine, and chlorine are present in small amounts. The central marrow and soft bony tissues are permeated by blood and lymph vessels and nerves. When burned, bones leave from one third to one half their weight as ash, which is nearly nine tenths tricalcium phosphate.

The vital organs include the brain, heart, lungs and the several organs of digestion. The tissues from which they are formed consist principally of protein compounds. Indeed, these compounds furnish the chief material from which is constructed the framework of every individual cell of the animal body. There is in animals no special cell-wall compound like cellulose of plants. The protein frame work of some cells may be more or less filled with fats.

Muscles are the chief organs in which occur the reactions of oxidation which provide the body with heat and energy, or power. It is heat provided in this way which keeps the bodies of common animals at a temperature of 98° to 100° Fahrenheit, even during cold weather. The muscles are attached by both ends to the bones, so that their contractions move the various parts of the body. They also round out and give form to the body. They are composed of a tissue of protein compounds bathed by a fluid containing dextrose, salts and other compounds.

The skin is primarily an organ of protection. Hair, nail, horn and hoof are special outgrowths from it. Cartilage and tendon are related to it. These tissues are all composed of modified forms of protein compounds. The elasticity of the skin is due to elastin. In cartilage, or gristle, the chief compound is collagen. By soaking bones in hot water the collagen of the cartilage and tendons is made soluble. On cooling the extract, gelatin solidifies from it. This compound is, as you know, much used for making jelly-like desserts. It contains about 0.6 per cent of sulphur. The chief compound of hair, wool, feathers, hoof, horn and related tissues is keratin. This protein is so severely modified from the simple form that it is much more resistant than even collagen. It becomes soluble, however, by heating with steam under pressure and forms glue. Keratin is much richer in sulphur than common proteins. It contains four or five per cent of the element. All these compounds related to the skin are very resistant and durable and well suited to their duties of protection.

Blood consists of a liquid part, the plasma, in which are suspended a great many discs of microscopic size. These discs are the red and white corpuscles. They form about one third of the total bulk of the blood, the red ones producing the characteristic scarlet color. Have you ever observed carefully the clotting of blood soon after it comes from the body? The dark red clot is formed by corpuscles entangled in threads of a protein called fibrin which gradually separates from the liquid. Calcium salts play an important part in this process. The clot is not the only product resulting from the process, however. It is surrounded by a yellowish liquid, the serum. This part of the blood is now much used in bacteriological and medical work, as in treating hog cholera. In chemical composition the blood consists of about four fifths water. Of the remaining solid part, over three fourths is protein compounds. The most abundant of these compounds is haemo-globin, which gives the red color to the blood. This compound contains about one half of one per cent of iron, to which it seems to owe its power to combine with oxygen. It unites with oxygen to form oxyhaemo-globin, changing from purple to scarlet in color. The blood contains small amounts of proteins and related compounds moving either to the tissues as food or to the excretory organs as waste products. It also contains a few tenths of one per cent of dextrose, and fatty compounds and ash-forming elements. Sodium chloride forms the greater part of the ash. Lymph closely resembles blood plasma in composition. There is much more fat in it, however, suspended in minute globules, which gives it a milky appearance. It serves as a medium through which compounds are exchanged between the blood and the tissues.

Nerves include a central mass of tissue known as the brain of higher animals. They differ distinctively from the other tissues we have studied by containing considerable amounts of nucleo-proteins. These compounds are complex combinations of proteins with organic, phosphorus-containing groups, the nucleic acids. They contain 0.5 to 1.5 per cent of phosphorus. Nucleo-proteins are most characteristic and abundant in those cells which bear the burden of reproduction. This fact shows how very important phosphorus is in life processes.

The composition of the bodies of animals has been carefully determined. Whole carcasses of steers and pigs have been analyzed for this purpose. These analyses have included both the most important compounds and the most abundant elements. All material in the digestive organs was removed before analyzing the bodies. From this work we learn the interesting fact that the body of a lean ox is two thirds water. Of the remaining solid matter over one half is protein, about one fourth is fat, and one fifth is ash forming elements. In a very fat ox, on the other hand, water forms but about one half the total bulk, while fat forms nearly one third of it. Of the solids in such an animal fat forms six tenths, protein three tenths, and ash about one twelfth.

We can see, then, that the chief difference between fat and lean animals is that the former contains more fat but less water than the latter. What, then, is the nature of the fattening process? It is the building of body tissues richer in fat and poorer in other compounds than usual. Such fatty tissue is about two thirds fat, and one fourth water, with small amounts of protein and ash-forming elements. These differences of composition are as true for the pig or any other animal as for the ox.

The elementary composition of the body, that is, its percentages of different chemical elements, is shown by the following interesting data for man given by Professor Kahlenberg of the University of Wisconsin.

Table VIII.—Average Elementary Composition of the Human Body

	Per Cent
Oxygen	66.0
Carbon	17.6
Hydrogen	10.1
Nitrogen	2.5
Calcium	1.5
Phosphorus	1.0
Potassium	0.4
Sodium	0.3
Chlorine	0.3
Sulphur	0.25
Magnesium	0.04
Iron	0.004
Silicon, Fluorine, Iodine, etc.	0.006
	100.000

We ought to make a brief survey of the meaning of the figures in this table. Oxygen and hydrogen, which together form over three fourths of the body, exist chiefly as constituents of water; but they are also abundant in the fats, proteins and other organic compounds. Carbon, which forms over one sixth of the body, by weight, is the keystone element of the organic compounds. Nitrogen and sulphur, though forming but a small part of the body, are necessary constituents of the very important protein compounds. Phosphorus occurs in nucleo-proteins, the calcium phosphate of bone and soluble phosphates of the tissue fluids. Potassium and calcium exist chiefly as phosphates, the former in fluids and the latter in bone. Sodium and chlorine, combined in sodium chloride, occur in the gastric juice of the stomach, in blood, and in other body fluids. Chlorine also occurs in hydrochloric acid of the gastric juice. Magnesium is present in salts of the body fluids and in bone. Iron is a part of the molecule of haemo-globin of red blood corpuscles. Silicon occurs in very small amounts in hair and feathers, and fluorine in bones.

It is well-nigh impossible to realize completely the great importance of oxygen to the body. As we shall see later, it enters into reactions at the very heart of life's processes. The importance of chemical elements in the body is not measured, however, by their amounts. In the long run, chlorine is quite as necessary as oxygen, though but one two hundred and twentieth as much is contained in the body. Moreover, iron is quite as essential as nitrogen, although there is less than one six-hundredth as much of the former as of the latter in the body. You can see that chlorine, apparently unessential to plants, takes a very definite place among the elements essential to animal life.

Comparison of Young and Mature Animals. A comparison of the composition of mature animals with that of young growing animals will show the nature of the tissues built during growth. For this purpose, we may choose cattle quite as well as any other animal. With the contents of the digestive tract removed, the fat calf consists of about 65 per cent water, 16.5 per cent protein, 14 per cent fat and 5 per cent ash. The fat ox contains only 50 per cent of water, but 30.5 per cent of fat, with about one per cent less protein and one half of one per cent less ash than the calf. This comparison shows that the growing animal produces tissue of protein nature, or lean meat, while the mature animal lays on fat. So, the composition of lean animals is about the same at all ages. The tissue made during growth contains about twice as much protein as fat, the two classes of compounds forming about three tenths of the body weight.

The proportions of those chemical elements most important in keeping up the fertility of the land are nearly the same in young and mature animals. Nitrogen forms, on the average, about 2.5 per cent of the body, phosphorus 0.7 per cent, potassium 1.5 per cent, and calcium 1.2 per cent. The pig, however, contains less of these elements than the other animals on account of the relative smallness of his bones and his greater tendency to fatten. From this fact, we see that the amounts of nitrogen and of ash-forming constituents depend chiefly upon the proportions of lean, protein tissue and of bony skeleton respectively. The fact that young and mature animals have practically the same composition shows that tissue of nearly constant composition is constructed as the animal grows.

The nutrition of the animal includes those processes by which growth is produced and the various tissues of the body are kept in repair. It embraces a complex series of chemical and physical reactions. There are four chief groups of the processes of nutrition, which succeed one another in the order named: Digestion, absorption, assimilation, excretion. Digestion includes those processes by which food is made ready for the cells of the body. Absorption includes the carrying of food to the cells. Assimilation covers the using of the food by the cells. Excretion removes unused food material and waste products of assimilation from the cells and the body. We shall now study these divisions of nutrition separately.

Digestion begins when food enters the mouth and ends when its products are ready for absorption by the blood and lymph.

Digestion in the Mouth. The first process to which the food is subjected is mastication, or chewing. In this process it is moistened by the saliva. This is a liquid secretion poured out by special organs called glands, located in the cheeks and beneath the tongue. It is a very watery fluid, containing not more than one per cent of solids. These solid substances are very important, however. Chief among them is the enzyme called ptyalin. This enzyme changes starch to maltose in a slightly alkaline medium. Saliva is slightly alkaline, due chiefly to the presence of bicarbonate and phosphate of potassium. Man secretes about a quart of this fluid daily. An ox secretes fifty times as much. Does this not show that the salivary glands are very active? Except possibly in cud-chewing animals, the food does not remain in the mouth long enough for much digestion to occur there. After it has been mixed with the saliva it is swallowed into the stomach through the oesophagus or "gullet." There the action of ptyalin continues. How does the difference of solubility between starch and maltose promise to render the work of ptyalin important in the later absorption of the food? Can you not suggest how chewing favors complete action of the saliva upon the food?

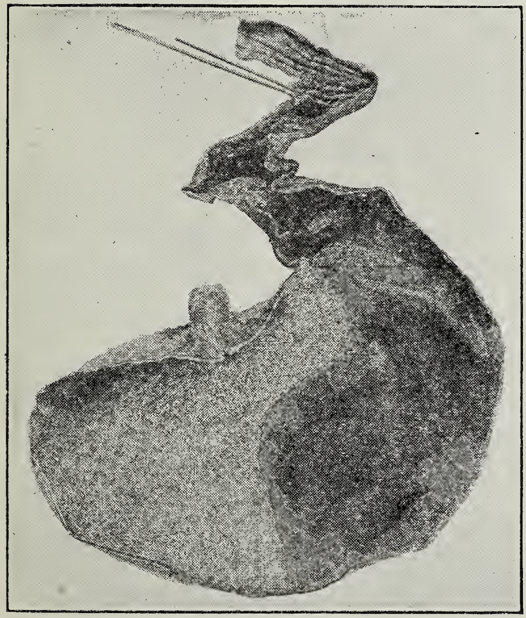


Figure 71. Stomach of the horse. The probes show the openings of pancreatic and bile ducts into the intestine.

Digestion in the Stomach. In the stomach the food is acted upon by the gastric juice. This is a secretion poured from the cells of the inner lining of the stomach. It is a watery fluid, like saliva, but is acid in reaction. You may have observed this acidity when some of the stomach contents has been returned to the mouth from an unsettled stomach. It is due to the presence of about 0.2 per cent HCl in the gastric juice. Digestion by saliva continues for a time in the forepart of the stomach. Gradually, however, the alkalinity of the saliva is neutralized by the acid of the gastric juice. Then, in the acid contents of the stomach, ptyalin is destroyed. The work of digestion is taken up at this point by enzymes of the gastric juice. Rennin and pepsin are the most important of these enzymes. The former coagulates or curdles the casein of milk. The latter, by causing cleaving reactions of the proteins with water, converts these relatively insoluble compounds into simpler, soluble compounds, the proteoses and peptones. From time to time, as the food is digested, the ring-like muscle at the pylorus relaxes. At the same time the muscular walls of the stomach contract and force the chyme, or contents of this organ, into the intestines.

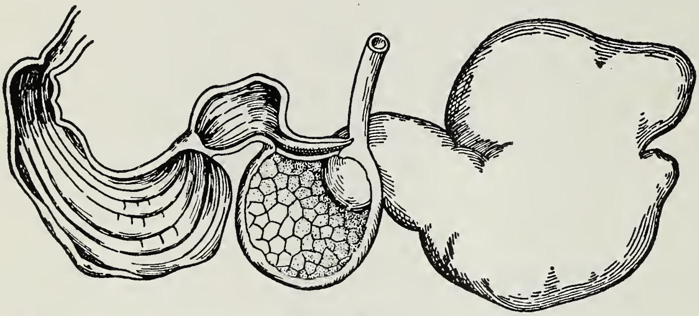


Figure 72. Stomach of a sheep. The parts of the sheep's stomach from right to left are: Rumen, reticulum, omasum or "manyplies" and abomasum or "rennet." The oesophagal groove is seen just over the reticulum.

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The stomach of ruminants, or cud-chewing animals, is much more complicated than that of man and the other non-ruminants. It consists of four parts, as shown in Figure 72. These parts, named in order from the oesophagus, are: (1) the rumen or paunch, (2) the reticulum or honeycomb, (3) the many-plies, and (4) the rennet. The paunch is a reservoir in which the coarse food may be stored until it is returned to the mouth for mastication. You must have sometimes observed the gullet movements by which the cow accomplishes this return to the mouth. The paunch of an ox is surprisingly large. It may reach a capacity of over fifty gallons. In it fermentation of the food occurs constantly, due to the action of bacteria and other organisms. The resulting gases are generally removed by the blood. Sometimes, though, animals gorge the paunch with easily fermentable material, such as green clover or fruit, and serious bloating occurs. In such cases the pressure of gases must be relieved by stabbing or "tapping" through the side of the body to prevent death.

The honeycomb receives food from both the gullet and the paunch. It is a sort of safety trap which catches in its rough lining such accidental objects as stones and pins. Look up in your dictionary the meaning of the adjective "reticulate." Does it show any reason for the scientific name "reticulum" applied to the honeycomb?

The many-plies, or third stomach, receives directly from the gullet such food as is in a finely-ground condition. This is done by the automatic closing of the slit opening into the honeycomb. An arrangement called the oesophagal groove is thus formed which directs the food to the third stomach. The lining of this part of the stomach is thrown up into folds which have a grinding action somewhat like that of the gizzard of fowls.

The rennet, or fourth stomach, accomplishes the digestion by gastric juice. It is this part of the stomach which is very active in calves in secreting the enzyme rennin and is used for preparing rennet extract for cheese-making. Here, also, pepsin does its work in the way already described.

In fowls, as you know, the process of chewing and the action of saliva, are almost totally lacking. The crop of these animals has much the same uses as the paunch of ruminant animals. This is connected with the gizzard by an enlarged portion of the oesophagus which forms the first stomach. The gizzard is the chief digestive organ. Very likely you have seen its thick, muscular coat and its tough, wrinkled lining. It is very well suited to the grinding of tough food materials. The chewing and protein digesting of the fowl are done chiefly by this organ.

Digestion in the Intestines. The intestines consist of a long, slender, much-coiled part followed by a shorter, wide part. In the former part, or small intestine, both digestion and absorption occur. In the latter part, or large intestine, the undigested residues of the food and other waste products are assembled and expelled from the body. When one learns the total length of the intestines it is possible to realize what a large share of the work of digestion they can perform. This length ranges from about 80 feet in the pig to 190 feet in the ox. Movement of material along these organs is caused by muscular contractions which traverse them like waves from the stomach toward the anus, or excretory orifice.

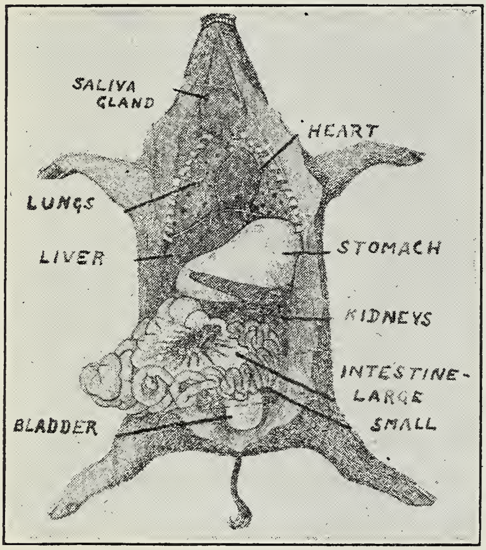

Figure 73. Some of the most important internal organs of the hog.

When the food mass enters the intestines from the stomach it has an acid reaction. This is soon neutralized, however, by alkalies and then the digestive action of the gastric juice ceases. The alkalies are contributed by the bile and the pancreatic juice. These are secretions from the liver and pancreas, or "sweetbread," respectively. They are poured into the intestines through openings near its union with the stomach. The pancreatic juice is slightly alkaline from its content of sodium carbonate. It also contains three important enzymes. These are trypsin, steapsin, and amylopsin. Trypsin takes up in this alkaline fluid the work dropped by pepsin, carries it much farther and reduces the proteins even to amino acids. Amylopsin continues the work of ptyalin, converting starch to maltose. This work is very completely done, as no starch is excreted from the body. Steapsin is related to the lipase of plant seeds. It converts fat into glycerine and fatty acids. All these enzymes act by hydrolysis, that is, by causing their respective compounds to unite with water and split asunder. The bile is the greenish liquid stored in a sac attached to the liver which is called the "gall bladder." It contains alkaline salts of sodium combined with organic acids. These help to neutralize the acid of the chyme; but, especially, they assist in the digestion and absorption of fats.

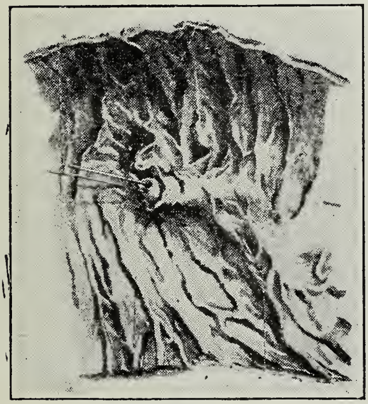

Figure 74. The inner wall of the small intestine near the stomach. Near the center can be seen the opening of ducts which discharge the pancreatic juice and bile.

The lining of the small intestines also secretes enzymes. One of these, maltase, changes maltose to glucose. Another, erepsin, splits digestion products of proteins completely to amino acids.

Absorption of Digested Food. All the various products of digestion, dextrose, amino acids, fatty acids and so on, are absorbed by the blood and lymph through the physical and chemical activity of the cells of the mucuos membrane lining the intestine. Figure 74 shows, as you can verify by observation, that this lining is thrown up into many folds. This arrangement greatly increases the absorbing surface over what a smooth lining would present. These folds are thickly threaded by blood capillaries and lymph vessels. Dextrose and protein digestion products find their way into the blood and are carried to the liver by a large vein. This organ converts any extra dextrose to a polysaccharide called glycogen. It also stores some of the excess of amino acids. When the food supply is low the glycogen is changed back to dextrose and the stored compounds are doled out to the blood. In this way it serves as a regulator of the composition of the blood. The fatty acids and glycerine are absorbed by the lymph converted to fats and passed into the blood in the neck. Undigested portions of the food pass from the large intestines as feces, or dung. With it are included the waste of fatty secretions from the bile and protein material added from dead tissue swept from the walls of the intestine and from bacteria which developed in this organ.

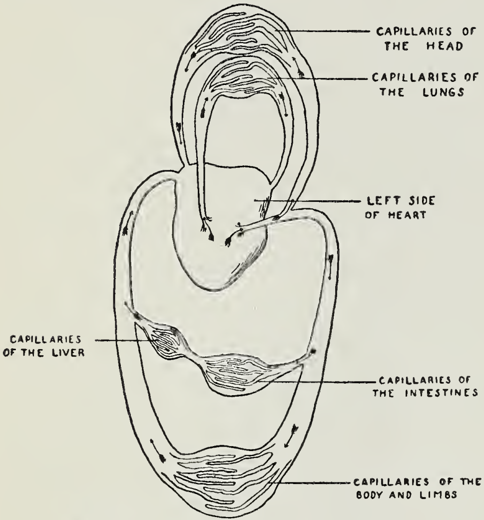

DIAGRAM OF BLOOD CIRCULATION

Figure 75.

Circulation of the blood carries the absorbed food compounds to the remotest tissues of the body. From the veins, as you learned in physiology, the blood is collected at the right side of the heart and forced to the lungs. Here the purple fluid of the veins is changed to the scarlet of the arteries and returned to the left side of the heart. This change of color is due to the absorption of oxygen from the air in the lungs. The arterial blood is pumped to all the tissues of the body. The individual cells of the tissues remove the oxygen and food compounds for work and building processes. They excrete their waste products into the purple blood which collects in the veins to begin the round of the body again.

Respiration is more than the mere physical act of breathing. It does not occur, as commonly thought, in the lungs. Breathing is merely one step in the process. The air which one exhales from the lungs contains only three fourths as much oxygen, but one hundred and fifty times as much carbon dioxide as the fresh air breathed in. This difference is due to the release of carbon dioxide from bicarbonate of sodium in the blood and to the taking up of oxygen to form the scarlet oxyhaemo-globin. Figure 76 shows how the much-divided tissue of the lungs thickly traversed by blood vessels favors a rapid exchange of gases between the air and blood. True respiration occurs only when this increased oxygen of the blood has reached the cells in need of it by the circulation already described.

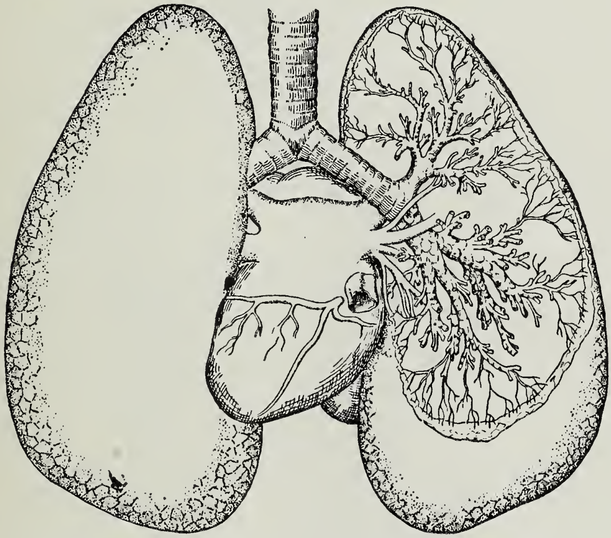

Figure 76. The lungs, showing their close relation to the heart.
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Assimilation includes the use of food compounds absorbed from the intestine and oxygen absorbed in the lungs. It occurs, as you can see, only when the bright, arterial blood reaches the particular cells in need. The chemical changes of growth and work are included in it. Certain food compounds, especially dextrose, are oxidized, or burned, to do work. This process is very rapid in the muscle cells when the body is doing outside work. Other compounds, especially proteins, are modified in various ways to build new cells and tissues.

Excretion is the process of getting rid of the wastes of the body. Not only must undigested food be expelled, but also the waste products from oxidation and growth in the various cells must be removed. What, for example, are the products of oxidation of dextrose when burned? Do you see in your answer an explanation for the large amount of carbon dioxide in venous blood?

Chief among the waste products from cells of the body, besides carbon dioxide and water, are salts and soluble nitrogen compounds resulting from proteins. The most abundant of these nitrogen compounds is urea, a close relative of ammonia.

The excretion of carbon dioxide occurs, as we have seen, from the lungs by way of the blood. Some water is also given off from the lungs, as you can prove for yourself by breathing against a windowpane in cold weather. As the breath is cooled it can no longer hold all the moisture present as it leaves the lungs. Hence water condenses in droplets upon the pane.

The skin also excretes water. Have you not observed in the case of your own body that vigorous exercise and rapid perspiration or "sweating" go hand-in-hand? This is a means by which the excess of water produced by oxidation in the cells of the working muscles is removed from the body. Nature has also wonderfully provided that the heat required to evaporate this perspiration shall cool the body. To this same end the dog instinctively pants with outstretched tongue to increase the evaporating surface of his body. That perspiration contains dissolved salts is well shown by its taste. What salt have you detected in it? It also contains various waste organic compounds.

The kidneys are the fourth important organ of excretion. As you see by Figure 77 the same principle is made use of in their structure as in the case of the lungs. Minute blood vessels thickly thread a mass of spongy tissue. The pores of this tissue increase in size toward the center, from which the urine is finally drained away for storage in the bladder. By their remarkable powers the cells of this organ receive on one side the waste-laden blood and excrete on the other side their special, selected product, the urine. The blood is then passed on, purified and ready to repeat its work of carrying both food and waste matter. The wastes removed from the blood by the kidneys are chiefly water, salts, and nitrogen compounds. Ordinarily they remove about as much water as all the other organs combined. In winter, however, when loss of water from the skin is small, the urine increases in amount. The kidneys, like the liver, are hard-working servants of the body.

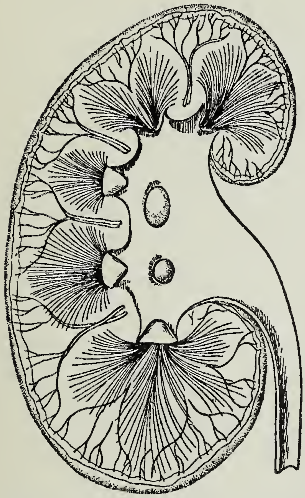


Figure 77. Section through a kidney and the channel leading to the bladder.

Measure of the Digestibility of Feeding Stuffs. The digestibility of a feeding stuff is measured by the difference between its dry matter and the dry matter of the dung produced from it. Generally, the digestibility of the protein and other constituents of the food are measured in this same way. Suppose, for example, 100 pounds of feeding stuff, containing 10 per cent of protein, produces 180 pounds of manure containing 3 per cent of protein. Then 10 pounds of protein are fed and 5.4 pounds are excreted. The digestibility of the protein of this feed is, therefore, 46 per cent. From what we learned about bacteria and other foreign matter excreted with the undigested food you can see that this method does not exactly measure digestibility. Yet it has been a valuable means for comparing the values of different feeding stuffs. At one time these measurements were made by catching the feces in a bag harnessed to the animal. The modern method is to place the animal in a cage of the sort shown in Figure 78. In such an apparatus both feces and urine can be accurately collected. By analyzing the urine chemists are learning a great deal about the way in which animals use the digested portion of the food.

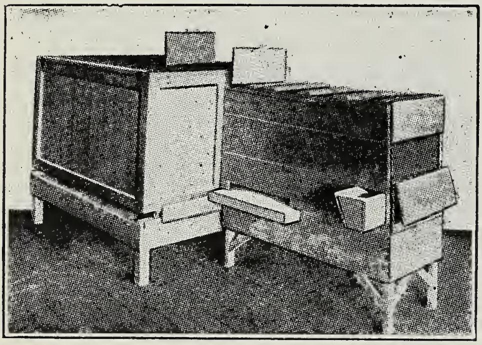


Figure 78. Cage used in digestion experiments. The larger part has a bottom of wire screening to catch feces and a sloping, tinned bottom beneath that to collect the urine. The smaller part is the feeding cage.

The products of farm animals vary a great deal in nature. That obtained from the horse is work. It may take the form of either speed of movement or pull, or "draft." In animals which serve for food, such as the pig, the product is meat composed chiefly of protein and fat compounds. These animals do work by their growth to provide a product for the use of man. It is just as truly work done by the cells of the body as is muscular exertion. The pig is by far the most efficient producer of this kind. When lean, his carcass dresses about three fourths of his live weight. The sheep and ox dress to only about one half of their live weight. This difference is due to the smallness of bones in the pig as compared with the other animals. Fattening mature animals produce very efficiently, as practically all the tissue they build forms valuable food for man. It is subject to little waste.

The sheep produces wool as well as meat. Pure wool is a protein compound, but the raw, unwashed material is coated with a greasy substance called "suint." This substance is a mixture of fats, soaps, salts, and other compounds left on the wool by evaporating perspiration. On account of the fatty nature of suint the raw wool is quite readily cleansed by washing with soap.

The cow produces milk in addition to meat. As we shall see later, this is a very special product of complex nature. It contains proteins, fats, sugar and characteristic salts. Tri-calcium phosphate is an important constituent of milk.

Fowls produce both meat and eggs. The latter contain chiefly protein compounds with smaller amounts of fats and related compounds. Since the egg performs the duty of reproduction, we find, as was learned of reproductive cells, that the phosphorus-containing nucleo-proteins are abundant in it. The egg shell is formed from calcium carbonate.

The relative efficiency of various animals to produce human foods from a given amount of feeding stuffs ought to be of great interest. It is given in the following figures. They represent the pounds of food produced from 100 pounds of digestible organic matter in feeding stuffs.

Cow, (in milk) 18.0; pig, 15.6; calf, 8.1; fowl, (in eggs) 5.1; fowl, (in meat) 4.2; steer, 2.5.

Notice what animal heads the list. She is followed closely by the pig, who far excels the other meat-producing animals. Do these relative producing values give you any insight to reasons why dairying is a profitable kind of farming? Do they suggest why the handling of pigs helps to make farming successful?

By-products Obtained from Animals. Several important by-products are obtained from animals. The preparation of several of them for use supports important industries. Leather is a by-product of the great beef-packing industry. Its preparation for use embraces the tanning industry.

Tanning consists in removing the hair and preserving the skin in a pliable condition. The hair is softened by the

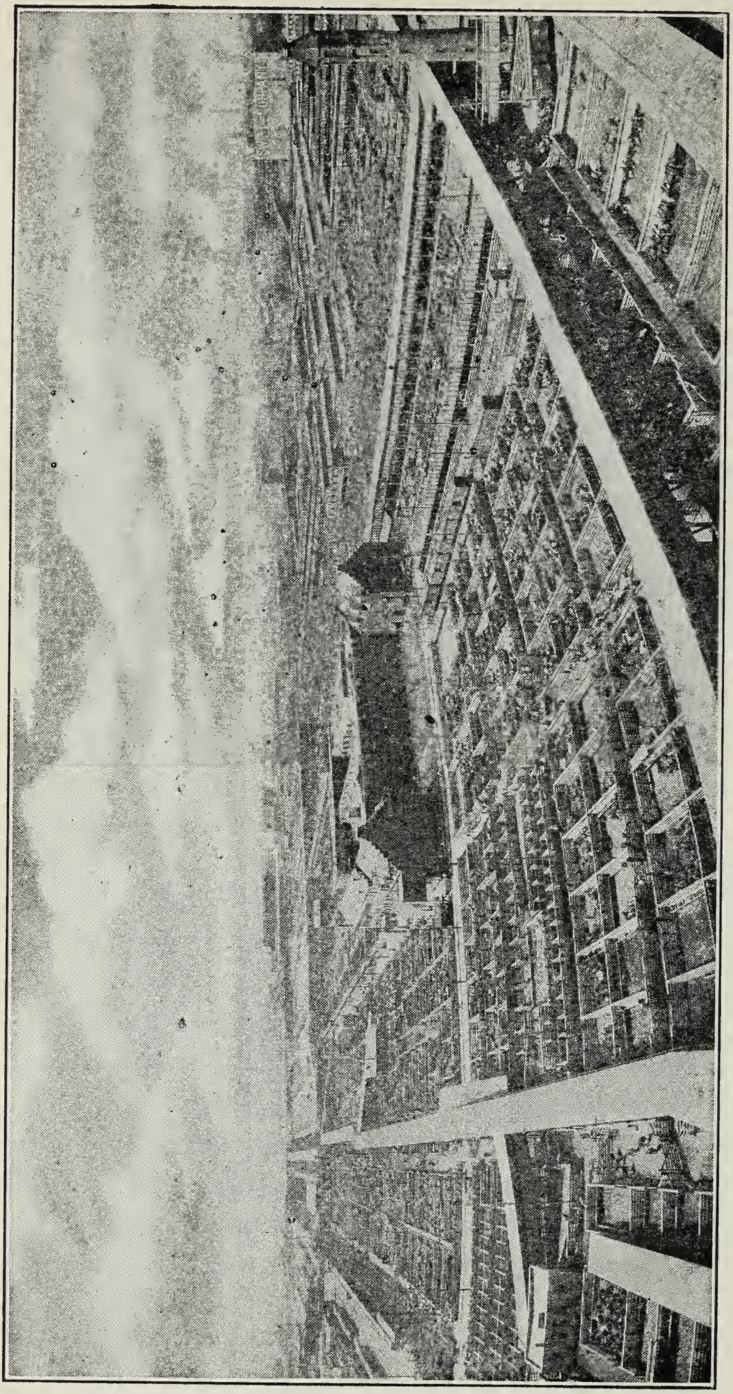


Figure 79. General view of the Union Stock Yards at Chicago. The dressing of animals for meat and the manufacture of by-products from the waste carcass form an enormous industry.—Courtesy of Swift & Co.

action of steam or of some slightly alkaline compound such as calcium sulphide, and scraped from the skin. We shall learn more about this loosening effect of the calcium sulphide when we study insecticides. After the hair is removed the skin is soaked in a solution of some preserving substance. Tannin, chromic oxide, and alum are commonly used. Tannin is extracted from barks, commonly from oak bark, for this purpose. It is a plant product closely related in its chemical composition to the coal tar compounds. By combining with the proteins it forms less soluble compounds which resist decay better than the natural protein matter of the skin. Chromic oxide acts by partly oxidizing the proteins of the skin.

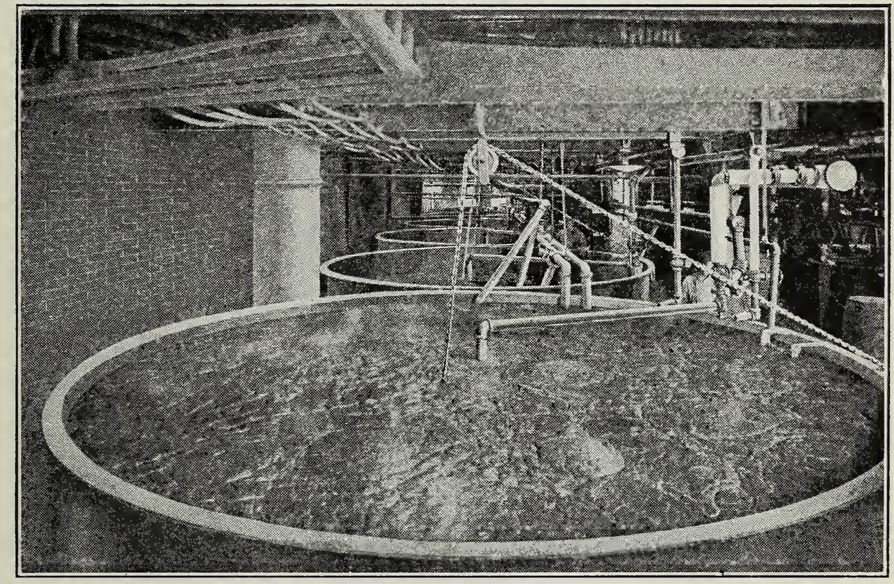


Figure 80. Making soap. Grease and alkali are boiled by steam in huge vats three or four stories deep. Soap is an important by-product of the meat-packing industry.—Courtesy of Swift & Co.

Tankage and dried blood are prepared from the wastes of the packing industry. The carcasses of condemned and aged animals are also made into these products. By quickly drying the materials in large steam-heated pans they are rid of bacteria and guarded from decay. They are also more cheaply handled after their water has been removed by drying. These products are valued as concentrated foods supplying protein and ash for pigs and fowls. Their greatest use, however, is as sources of nitrogen and phosphorus for fertilizers. Gelatine, mentioned before, is a product obtained by steaming cartilage and tendon tissues. Glue is made in this way from hoof and horn. Horn is also cut into buttons and many other useful articles.

SUMMARY

The body of the living animal is a wonderfully arranged, automatic factory. Materials by which this factory keeps in repair and fuel from which it obtains power are provided by plants in the form of food.

In structure the body consists of the skeleton, vital organs, muscles and skin. The actions of these various parts are brought into harmony by the nerves. Their chemical reactions are inter-related through the blood and its circulation.

In chemical composition the bony skeleton is chiefly tri-calcium phosphate and the other organs are mixtures of protein compounds. Hair, horn and hoof are modified forms of the skin proteins.

Water forms the greater part of the weight of animals. The remainder of the body is chiefly proteins in lean animals and fats in fat animals. Oxygen forms two thirds of the body weight, while several other elements occur in amounts from a trace to a few per cent. Some of the elements present in small amount, such as chlorine, are as essential to life in the long run as oxygen. Those elements important in the fertility of the soil are present in smaller amounts in the pig than in other animals, for the reason, previously stated that it has a low proportion of bone and a high proportion of fat in its body.

Animal nutrition includes the physical and chemical processes which repair and increase the tissues of the body. Its four chief steps are digestion, absorption, assimilation and excretion. Digestion is performed by enzymes contained in fluids secreted by special organs called "glands." It occurs not only in the mouth and stomach, but also in the intestine. Digestion reduces the compounds of the food to soluble products. Absorption is the process in which these products are taken up through the intestine wall into the circulating blood and carried to the tissues. It includes the taking up of oxygen by the blood in the lungs. Water is of great importance in the chemical reactions of digestion and the physical processes of absorption. Assimilation includes the processes in which oxygen and products of digestion are removed from the blood and used by the various cells in need. The assimilation of oxygen is separately known as "respiration." Excretion is the process of removal of waste products from chemical reactions in the various cells of the body. It covers the absorption of these compounds by the blood and their final expulsion from the lungs, skin and kidneys. Undigested feeding stuff and some waste materials are excreted by the intestine. The difference between the composition of the food and of the intestinal excreta produced from it is used as a measure of the digestibility of feeding stuffs.

The products of animals made use of by man are work and food. In power to produce human food from a given amount of their feeding stuffs the milch cow and the pig far excel other farm animals. Dairying and the handling of swine have come, therefore, to be the most generally profitable kinds of farming. By-products from the great meat-packing industries provide in themselves industries of considerable importance. They include leather, tankage, glue and horn articles.

QUESTIONS

1. What is the composition of bones?
2. What is the composition of the muscles and vital organs?
3. What is the composition of hæmoglobin? Its functions?
4. What are the chief compounds of nerve tissue?
5. How much water is there in the body of a lean ox?
6. What chemical element is most abundant in the human body?
7. What element unessential to plants is essential to animals?
8. What is the action of saliva on foods?
9. What is the action of gastric juice upon the foods?
10. What three important enzymes are in pancreatic juice?
11. What work does each perform?
12. What digestive process is assisted by the bile?
13. What effects does the liver exert on the composition of the blood?
14. What compounds of the food are absorbed by the lymph after digestion?
15. What important chemical change occurs to the blood in the lungs?
16. Where does assimilation of the digested food occur?
17. What is the source of the carbon dioxide excreted from the lungs? Of the water excreted in perspiration?
18. What wastes are excreted by the kidneys?
19. How is the digestibility of feeding stuffs measured?
20. What are the chief compounds of milk? Of eggs?
21. What two animals excel as producers of human food?
22. How are hides tanned?
23. How are gelatine and glue made?

CHAPTER XI

THE FEEDING OF ANIMALS

Scientific Foundation of Feeding. On the title page of his well-known book "Feeds and Feeding," Professor Henry has placed the following German adage: "The eye of the master fattens his cattle." It is, indeed, true that a watchful eye is necessary to the farmer who would secure the best possible returns from the feeding of animals. Perhaps you know such a master-feeder in your own neighborhood. He must be a man quick to detect the response of each of his animals to different kinds of treatment. In the past, the observations of such keen stockmen have created quite a compendium of opinions on the subject of feeding. These opinions have the attractive quality of being expressed in simple and very practical language. Much faith has been placed in them by the average farmer. We must remember, however, that at best they express but roughly some of the scientific principles which underlie the nutrition of the animal. Like other arts, the feeding of animals has undergone sure and rapid development only when guided by scientific principles. It is clearly recognized by scientists that uniform and sure results can be obtained by the feeder in but one way. That way is pointed out by principles carefully determined by studies in chemistry and physiology. We, therefore, ought to study, in as simple terms as possible, the scientific principles which regulate the feeding of animals.

Nature and Composition of Feeding Stuffs. In our study of the animal we learned that its body resembles a factory for which food serves as repair material and fuel. Let us now inquire into the nature and composition of feeding stuffs. These food substances consist of a great number of compounds which the chemist divides by analysis into six groups. These are: water, protein, fat, fiber, nitrogen-free extract, and ash. The amount of water varies greatly between fresh and cured feeding stuffs. Turnips and other roots contain about 90 per cent, green fodders contain about 80 per cent, and cured grains and hays, in the condition called "air dried," contain only about 10 to 15 per cent. The term "crude protein" includes all the nitrogen compounds of the feeding stuff. For our purposes it may be regarded as consisting of protein compounds. Its amount varies widely. Only one or two per cent is present in fresh root crops and green hays, but in cured clover and legume hays and in grains 10 to 14 per cent is present. In some special grain products, such as cottonseed meal, protein forms almost one half of the material. The amount of fat varies from a few tenths of one per cent in root crops and green hays to about 5 per cent in grains. It is commonly called "ether extract." This is a more correct name than fat, because chlorophyll, which is not a fat, forms a large part of the material extracted from hay by ether. Fiber is a mixture of cellulose compounds. The impure product separated by the chemist is called "crude fiber." Its amount varies from 2 per cent in some grains to 30 per cent in some hays. Nitrogen-free extract includes chiefly starch and other carbohydrates made soluble by boiling the feeding stuff with weak acid and weak alkali successively. Do you not see that it is, indeed, an extract material free from nitrogen? Its amount varies from about 40 per cent in hays to 70 per cent or more in grains and mill products. The reason for separating fiber from the other carbohydrates in analysis will become clear when we learn how slight is its service to the animal. The ash includes those elements recombined and left behind by burning, as already described in the chapter upon the plant. Its amount ranges from 1 per cent in green fodders and some grains to nearly 6 per cent in wheat bran and other mill products. Of these several groups of compounds only four will need much of our attention. These are the protein, fat, nitrogen-free extract, and ash. It will be helpful to think of the nitrogen-free extract simply as digestible carbohydrates. Now we can regard the uses of these compounds in the feeding of the animal.

Building and Fuel Values of Feeding Stuffs. On the one hand, proteins are the important building and repairing materials of the food. On the other hand, fats and carbohydrates serve as the sources of heat and power. We have seen that each cell of the animal body is constructed chiefly from proteins. Growth makes necessary an increase of this protein material. The destructive effects of work makes necessary its repair. We should realize that the protein compounds of feeding stuffs supply these needs. No other compounds of the food can replace proteins in this work; for no other compounds contain the necessary bricks from which to build proteins of the body.

The bomb calorimeter is an instrument by which one can measure the heating power of feeding stuffs. The different compounds and elements of feeding stuffs can also be compared by it. One measures their fuel value by burning them completely in a strong steel chamber or "bomb" with a liberal supply of oxygen. Why will not common air do? The heat produced warms the bomb and, as you see by Figure 81, is transmitted to a definite weight of water surrounding it. It is necessary to protect the water from loss of heat to the air. The question now arises: How shall the amount of heat be expressed? It is expressed in units called Calories. You will find it interesting to consult a large dictionary and learn the origin of this word. It is the quantity of heat required to raise one kilogram of water from 0 to 1 degree on the Centigrade scale. A degree Centigrade is 1.8 times as great as a degree Fahrenheit and the zero of this scale is equal to 32° Fahrenheit. There are

2.2 pounds in a kilogram. With these values you can, if you choose, compute the value of a calorie in pounds of water and degrees Fahrenheit.

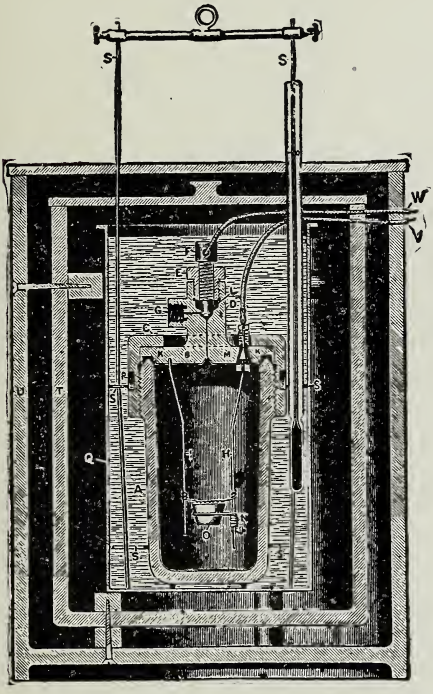


Figure 81. The bomb calorimeter. Feeding stuffs are compressed into pellets which are ignited by electricity in the small, suspended cup and burned in an excess of oxygen.—Courtesy of Eimer and Amend.

The fuel values in calories per gram of some important elements and compounds of feeding stuffs are: Carbon (charcoal) 8.00, hydrogen, 34.40, protein (wheat gluten) 6.00, carbohydrate (sucrose) 4.00, fat (olive oil) 9.50. These fuel values are also spoken of as "energy values," because, like the heat generated by fuel under the boiler of a steam engine, they represent power to do work, when set free by oxidation in the animal body. From the preceding values we see that hydrogen is far superior to the other elements as fuel. This fact is made use of in a very practical way in the oxy-hydrogen blowpipe, an instrument which develops great heat by the combustion of a stream of hydrogen gas in oxygen. Note the difference of the fuel value between carbon and carbohydrate. Does it suggest why the blacksmith chooses charcoal in preference to coal and wood for his forge? Kerosene and other petroleum oils owe their heating properties to the mixtures of hydrocarbons which they contain. These compounds, containing only carbon and hydrogen, produce more heat than an equal weight of the common organic compounds of feeding stuffs. The lower value of the latter compounds is due to the presence of oxygen in them. They are already partly satisfied by oxygen. Our values show that proteins, for an equal weight of substance, produce about 1.5 times as much heat as carbohydrates. Fats are much more efficient and produce 2.4 times as much heat as the carbohydrates. These differences are due to differences in the amounts of carbon, hydrogen and oxygen contained in these compounds. Examine the following figures and compare the percentages of carbon with the fuel value of each compound. Do the same for hydrogen. Do the same for oxygen.

Table IX. The Relation of Composition to Fuel Value of the Compounds of Feeding Stuffs.

Per Cent of	In the Carbohydrate Dextrose	In the Protein Zein, of corn grain	In the Fat Olein, of olive oil
Carbon	40.0	55.2	76.6
Hydrogen	6.7	7.3	12.1
Oxygen	53.3	20.8	11.3
Nitrogen and sulphur	0.0	16.7	0.0
Total	100.0	100.0	100.0

Do you not see that fat owes its high fuel value to a high ratio of carbon and hydrogen to oxygen? Carbohydrates have the lowest fuel value because already most satisfied by oxygen. We can see, then, that different proportions of these compounds in feeding stuffs must produce different fuel values for materials so widely different in composition as timothy hay and gluten feed. The amounts of heat developed by such portions of feeding stuffs as are handled in making rations are too great for convenient expression in calories. Professor Armsby, of the Pennsylvania Experiment Station, has, therefore, used the newer value of therm. A therm is one thousand times as large as a calorie. The fuel values of 100 pounds of some common feeding stuffs are as follows: Cornmeal, 171 therms; timothy hay, 175 therms; linseed meal, 197 therms.

We must remember that these fuel values measured by the bomb calorimeter are quite different from the final fuel values of the feeding stuffs to the animal. In the bomb calorimeter, you will recall, the feeding stuff is completely oxidized. Is this true in the animal body? Suppose we were to dry the feces. Would they not burn and give heat? The urine also can be evaporated. Compounds left there by incomplete oxidation in the animal can then be burned in the calorimeter. So there are two ways in which unused fuel material escapes the animal: (1) undigested fuel compounds, like cellulose, which pass out with the feces; and (2) waste products from digestion which have fuel value, such as organic compounds of the urine.

Value of Indigestible Roughage. The undigestible cellulose of feeding stuffs resembles in a way the waste clinkers found in coal ash. Yet it is not entirely useless. It keeps the material in the intestines loose. It also has an irritating effect which causes beneficial movements of these organs. Perhaps you have noticed that farmers avoid using alone such feeding stuffs as cottonseed meal, which are known as "concentrates" on account of their richness in food compounds. They realize that a certain amount of "roughage," which includes fibrous feeding stuffs, such as hay, prevents constipation. On the other hand, there is danger of feeding too much fiber in the ration, because, in addition to its own indigestibility, it reduces the digestible amounts of other food compounds by protecting them from the digestive fluids of the animal. We can think of the cell walls of tissues in the feeding stuff as protecting the contents of uncrushed cells in this way. The compounds of the second class in which fuel value leaves the body are chiefly urea and other nitrogen compounds of the urine. These organic compounds, as you will recall, are waste products from the chemical changes which proteins undergo in the body. Since they are not completely oxidized, they represent a loss of part of the fuel value of the feeding stuff. To the fuel value of these compounds must be added that of gases produced by fermentation in the intestines. The chief of these is methane or marsh gas, a hydrocarbon which gives considerable heat when burned. It is a waste product of digestion and contains unused fuel value.

Productive Value of Feeding Stuffs. From these statements you can see that there are several causes which make the use of the fuel value of feeding stuffs incomplete to the animal. In feeding science the fuel value of these waste products of digestion is subtracted from the fuel value of the ration to give what is called "the available energy." Our study of fuel value does not end here. The farmer naturally wants to know most how much working or producing fuel value there is in his feeding stuffs. He wants the matter boiled down to the merchant's term of "net profit." Putting his problem in terms of the steam engine, he wants to know how much power to expect after his fuel material has burned and heated the boiler. One more item must be subtracted from the total fuel value of the feeding stuff to obtain this final effective part, called the "productive fuel value." This last item is the loss of fuel value or energy due to the muscular work required of the jaws and intestines. It ought to be readily clear that much more work is required for chewing a pound of fibrous timothy hay than for the same amount of non-fibrous cornmeal. The following statement will show how great this difference is. One hundred pounds each of these two feeding stuffs contain fuel value to the amount of 171 and 179 therms. Dr. Zuntz, of Germany, measured the extra amounts of oxygen required by a horse when chewing these two kinds of feed. He found that twelve times as much fuel value was required to chew a hundred pounds of hay as were required by an equal weight of corn grain. With the further work needed to digest it and excrete the wastes, only one half of the fuel value digested from hay is left for "productive fuel value" in the animal.

This is the great secret as to why grains and mill feeds fatten cattle and keep horses in condition, while hay alone will not do so. So much of the fuel value of hay is used in the work of digestion that little is left for the use of the animal. There may be enough left for the needs of the resting animal, but when there is work to be done, either in fattening or in muscular effort, grains or their mill products must be included in the rations.

Have you ever wondered why animals which eat hay are not fed the straws, and especially wheat straw? Little productive value is left from the work of digesting the straw. For a resting animal 2.4 pounds of wheat straw are equal to a pound of corn grain; but, when work is required, 8.6 pounds of it are necessary to replace a pound of the corn. Such a feeding stuff hardly repays the working animal for the work required in passing it through his body.

The Nutritive Ratio. A scientific basis for feeding animals based upon the principles we have just been studying was first used about 1864. Half a century before that a very crude standard was proposed by which meadow hay was taken as the basis with which to compare different feeding stuffs. Probably the need of some such step as this had been realized many years earlier. We owe the present method of measuring the values of feeding stuffs by their digestible food compounds, or digestible nutrients, to the German scientist, Dr. Wolff. A great deal of work has been done by many investigators of nutrition to obtain the needed values of digestibility of the nutrients in various feeding stuffs. One of the most interesting facts about this work is that it shows great differences between the digesting power of ruminant and non-ruminant animals. The ruminants, as we might expect, from their more complicated stomach, have the greater digestive power. For example, the horse digests only about 21 per cent of the protein of timothy hay, while the cow digests about 47 per cent. For the carbohydrates other than cellulose, or the nitrogen-free extract, the respective percentages are 47 and 62. The fat differs in the same way. As has been explained before, the greater digestion of the nutrients by ruminants than by non-ruminants is due chiefly to their greater power to digest cellulose. This difference in digestive power is true of timothy hay, for cattle digest about 53% of the crude fibre of timothy hay, while horses digest only 43% of it. In expressing the values of feeding stuffs their digestible part is treated so as to compare the building protein compounds with the heating fats and carbohydrates. This expression is called the "Nutritive Ratio." It is the ratio of the weight of digestible protein to the combined weight of the other digestible organic compounds expressed as fuel value of carbohydrates. For the reason already explained, fat is given 2.4 times the value of carbohydrate in this ratio. The numerical value of the nutritive ratio is found by the following proportion: Digestible protein: [digestible carbohydrate + (2.4 × digestible fat)] = 1 : x.

We can calculate the nutritive ratio of wheat bran for cattle by consulting tables of digestibility in a standard book on feeding, such as Professor Henry's. In such tables we shall find the percentages of the total nutrients which are digestible called "Coefficients of Digestibility." The percentage of the total protein, fat, nitrogen-free extract and fiber in wheat bran are 15.4; 4.0; 53.9, and 9.0, respectively. Of these total amounts in 100 pounds of the feeding stuff there are digested by cattle the following percentages of the respective constituents: 77.8, 68.0, 69.4, and 28.6. Multiplying the total per cent of each constituent by its percentage of digestibility and using the values in the proportion just given, we can find the nutritive ratio. The crude fiber and nitrogen-free extract are combined to give the value for carbohydrates. Therefore the nutritive ratio is:

$$11.98 : [37.4+2.57+(2.4\times 2.72)] = 11.98 : 46.50. = 1 : 3.88.$$

This is a "narrow" ratio, that is it contains a high ratio of protein to fuel value. Barley meal has the "medium" nutritive ratio of about 1:8. Timothy hay, on the other hand, has a ratio of about 1:17, which is regarded as "wide." It will be well worth while for you to calculate the nutritive ratios of other kinds of feeding stuffs, such as oat straw, rutabagas, and linseed meal. Calculate also the nutritive ratio of one or more of these feeds when fed to the horse or pig, and compare it with the corresponding value for cattle.

A narrow nutritive ratio of the animal's mixed ration is important where either rapid growth or the production of milk is required. This is why blood meal is beneficial to young pigs, oil meal to calves, and cottonseed meal to dairy cows. For maintaining a resting, mature animal, feeding stuffs of wide nutritive ratio, such as timothy hay, are sufficient. For fattening purposes, where considerable fuel value and a moderate amount of protein are required, a medium ratio is effective. That is why corn meal serves very well, as you may have learned, for fattening. In feeding practice it is usual to vary the nutritive ratio from 1:4 for young animals to 1:12 for resting, mature animals.

Individual Differences in Food Requirement. We should remember that the feeding of animals is quite different from performing chemical experiments. In a chemical experiment one can calculate just what quantities of materials are required to produce a given amount of product. Not so, however, with feeding! For, though the use of the food consists largely of chemical reactions, the latter are too numerous and complicated to permit as yet calculation of the amounts of compounds reacting. Furthermore, the living animal is a far different sort of reaction vessel than a beaker or test tube. On account of their complex mechanism, no two individuals give just the same results from a given amount of feeding stuffs. Even the same animal gives different results at different times, depending upon the continually changing condition of its body. So you see there is need for the "eye of the master" to co-operate with the scientific principles of feedings.

Mother's Milk a Guide. Nature's choice for the food of the young animal gives man a scientific basis upon which to begin feeding when weaning is done. The mother's milk is a highly specialized food balanced in composition to meet the needs of the rapidly growing body. Chemical analysis has disclosed the important fact that those animals whose young mature most rapidly produce milk richest in protein and in ash constituents. For example, the ewe, whose young requires fifteen days to double its weight, yields milk containing 4.9 per cent of protein and 0.84 per cent of ash. Woman, on the other hand, whose young doubles its weight in one hundred eighty days, or twelve times the period required by sheep, produces milk which contains only 1.6 per cent of protein and 0.2 per cent of ash. Since the ash of milk consists largely of calcium phosphate, we see here emphasized the great importance of this compound and of protein in the processes of building muscle and skele-

Figure 82. Lack of phosphorus in their rations crippled these pigs by weakening their bones.

ton. The nutritive ratio of milk is narrow. It ranges from 1:2 for the sow to 1:4 for the cow. It is important in feeding to remember that the mother with young has the same sort of demands to supply as the young animal. She should, therefore, receive rations containing liberal amounts of protein, calcium and phosphorus. You might look up some tables giving the composition of feeding stuffs and select some mill products you would recommend for her ration. For example, clover or alfalfa hay is especially valuable as a source of calcium.

Ash Constituents. Proper kinds and amounts of ash constituents are very important in the food of animals. Sometimes serious trouble comes from a lack of either phosphorus or calcium. Pigs fed almost entirely on corn or corn feeds often lose the use of their legs. At first their hind parts weaken and finally they are unable to walk. Corn grain is very poor in calcium. It contains a good deal of phosphorus, but that does the animal little good, if it gets no calcium to combine with it for making calcium phosphate of the bones. In like manner, horses fed too exclusively upon grains often develop a porous condition of the bones called "millers' horse disease" or "bran rachitis." This trouble is also due to an improper ratio between calcium and phosphorus in the food. There are in a molecule of tricalcium phosphate, the chief constituent of bones, three atoms of calcium, each having an atomic weight of 40. There are present also two atoms of phosphorus, each with an atomic weight of 31. Thus there are 120 parts of calcium to 62 parts of phosphorus, by weight. What is the ratio of calcium to one part of phosphorus? The following are the ratios of calcium to one part of phosphorus in the feeding stuffs named: Corn grain, 0.07; oats grain, 0.26; potatoes, 0.25; turnips, 1.36; meadow hay, 3.72; clover hay, 5.90; alfalfa hay, 7.84. We recall here, as was learned in the study of the plant, that phosphorus accumulates in the seeds of plants, but calcium is most abundant in the straws. Which of these feeding stuffs would you select to make up the deficiency of the corn grain in calcium?

The fuel needs of the animal are measured by an apparatus called the respiration calorimeter. This is an air-tight chamber in which the animal can be confined, and, as the name indicates, its products of respiration and heat production can be accurately measured. Analyzed air, containing a proper amount of water, is forced into the chamber and the escaping air is also carefully analyzed. Very slight changes of temperature within the chamber can also be measured very accurately. One of the important findings of this apparatus is that small animals require more

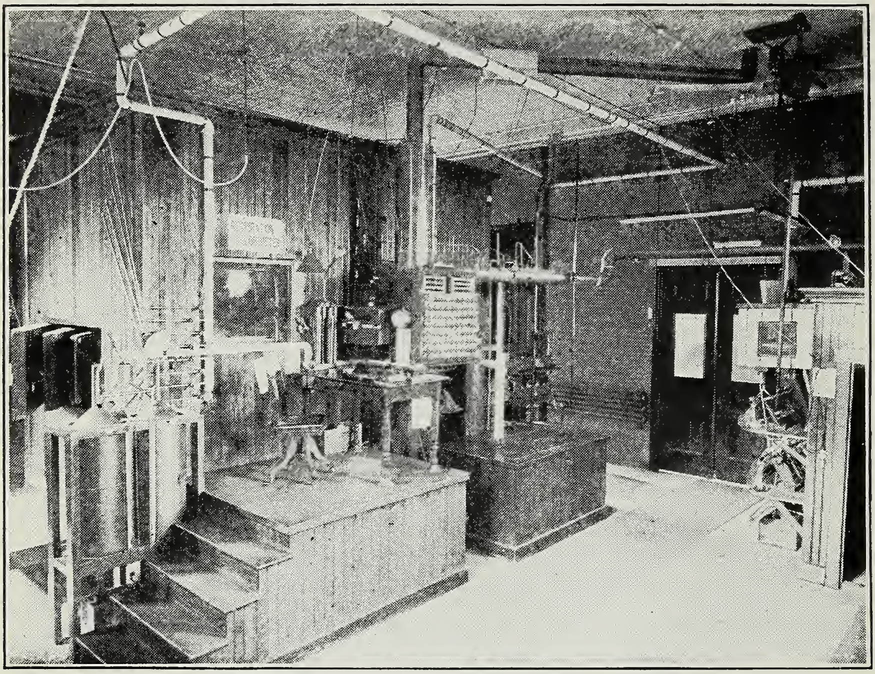


Figure 83. The respiration calorimeter used by Dr. Armsby in studying the food requirements of animals. The doors at the left show how the walls are built in separated parts to prevent the loss of heat to the outer room. Some of the apparatus in view is for preparing the air supplied to the calorimeter and measuring the gases removed from it.

fuel value in their food per pounds of their weight than do large animals. From your study of soils you will recall that a pound of clay contains more surface on its particles than does a pound of coarse sand, because small spherical bodies possess more surface in proportion to their bulk than large ones. The same fact applies to animals. On account of this greater proportion of surface to weight, a small animal loses more heat into the air in proportion to its weight than a large animal. The amount of heat lost from a square inch of body surface is nearly the same for all animals. If we select the dog and the mouse for comparison, both animals being at rest, we shall find that the former produces only about one fifth as much heat per pound of weight as the latter. The horse produces about one twentieth as much heat per pound of weight as the mouse. Thus we see that young and small animals need more liberal supplies of carbohydrates and fat than mature and large animals.

The rate, or severity, of labor is another thing which regulates the demand for food. When the oxygen used by the animal is increasing, we know that more fuel value is being required of the food. The greater consumption of oxygen shows that more food is being burned in the body tissues. The great German scien-

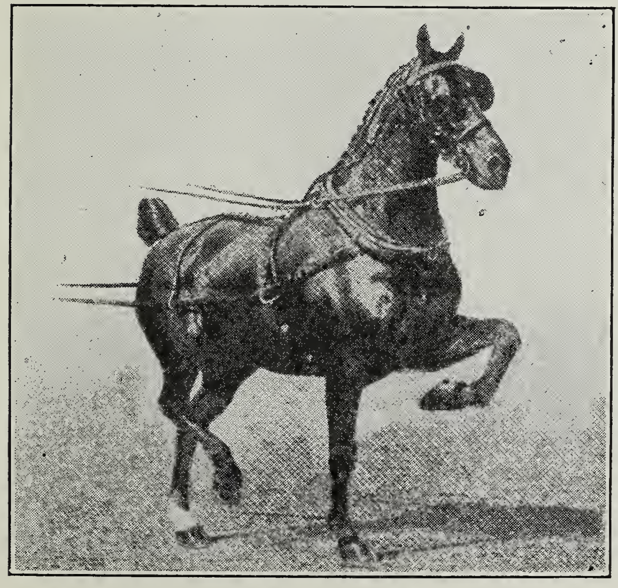


Figure 84. A spirited hackney. His movements require energy or fuel value from his food.

tist, Dr. Zuntz, has devised a silver tube to be inerted in the trachea, or windpipe, of the horse, so that the oxygen used by it can be measured readily. By this means it has been learned that increasing the speed over a given distance increases the amount of food required. Changing from a slow walk to a trot three times as rapid doubles the food requirement. Horses of high action, such as hackneys and coaches, which do much work in lifting the body, require especially high food values. The fact that this action increases the food requirements explains their almost insatiable appetite at times.

Need of Proteins. Muscular work causes a destruction of tissue, which must be repaired. So we find that increase in its severity increases the need of proteins as well as of carbohydrates and fats. Besides, especially with the milch cow, some excess of protein above the actual need for repairs is necessary for the best results. Protein seems to act in some way as a tonic stimulating the milk-producing cells and other cells of the body to their best efforts.

Special Needs. The special products of some animals create special needs in feeding. Wool, eggs and milk, on account of the large proportion of proteins in their composition, require narrow nutritive ratios for the rations of the animals producing them. Wool is nearly pure protein. The solids of milk, that part left by drying, are over one fourth protein and those of eggs are about one half protein. The hard-working milch cow does best on a nutritive ratio of about 1:6.5. Young pasture grass, whose beneficial effect on the flow of milk is well known to farmers, has a ratio narrower than this. It would be interesting to know how much of its food so complicated a machine as the milch cow uses for different purposes. Director Jordan, of the New York State Experiment Station, has estimated that about one third of the fuel value of this animal's ration is required to maintain her body and one third is contained in the organic compounds of the milk. The remaining third of the fuel value is used in the work of producing the milk. Do you not see herein very good reasons why the dairy cow giving milk should receive oil meal, wheat bran and other concentrated mill feeds?

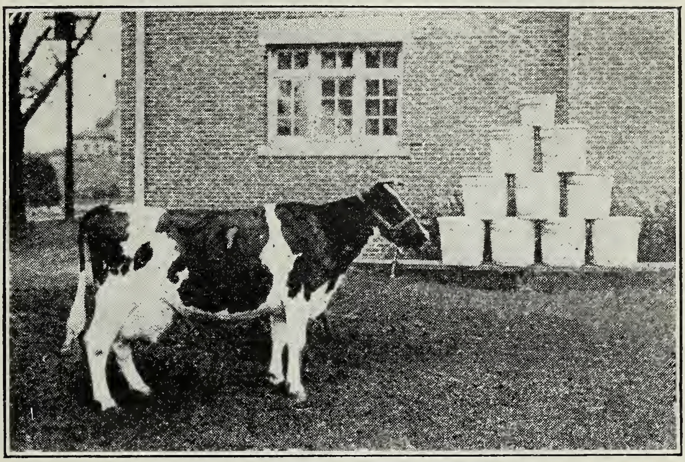


Figure 85. A high grade cow and her year's production of butter. She is the most efficient producer among the farm animals.

Working or producing animals are like long distance runners on the track team in this respect, that it is the final stages of their efforts that cost the most energy. Tired muscles and cells work less efficiently than fresh ones. For this reason the last few seconds clipped from a trotting

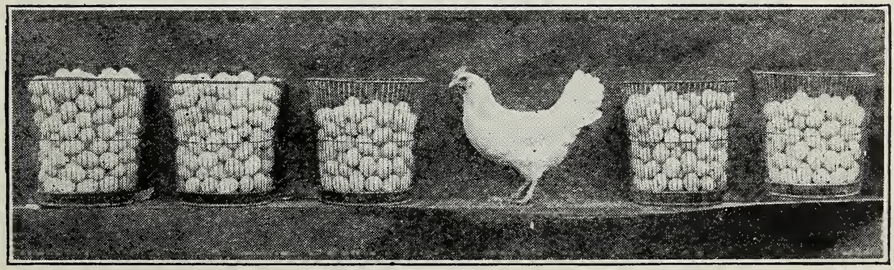


Figure 86. A prolific hen and her product of five years. Her efficiency is much lower than that of the cow.

record and the last few pounds of butter-fat in a record-breaking production cost much more in protein and fuel value than the same amounts of products from moderate work. It requires an extra allowance of food to support these extraordinary efforts. The feeder who desires them must exercise special skill.

Feeding Standards. Dr. Armsby, of the Pennsylvania Experiment Station, has spent many years in studying the food requirements of animals by the use of the respiration calorimeter. Professor Haecker, of the Minnesota Experiment Station, has made a thorough study of the food requirements of the dairy cow. We ought to know something about the lessons which these men have learned. It is not necessary to burden our mind with remembering the different amounts of food values which they recommend. It is important, however, for us to remember the scientific principles which they teach.

For a resting horse weighing 1,250 pounds, Dr. Armsby proposes 0.6 pounds of digestible protein in the food daily. When the animal is doing light work he recommends that 1 pound of the protein be fed. For heavy work he raises the amount to 2 pounds. He recommends raising the fuel value at the same time from 7.0 to 9.8 to 16.0 therms daily, as the work of the animal increases. There are two facts which you will see very plainly, if you will compare these different values. The first of these facts is, that, with increase of work, the need for protein increases more rapidly than that for fuel value. The second is that both of these needs increase rapidly as the amount of work increases. For growing cattle Dr. Armsby recommends 1.0 pound of digestible protein and 4.5 therms of fuel value daily when the animal weighs 250 pounds. A two-year-old weighing about 1,000 pounds should receive 1.75 pounds of protein and 8.6 therms. The important fact readily seen here is that the food requirements of the animal do not increase nearly as fast as its weight. While the body weight has increased four-fold in this example, the protein and fuel value required have not even doubled. For a milch cow weighing about 1,000 pounds, Professor Haecker recommends 0.7 pound of digestible protein and 7.2 pounds of digestible carbohydrates and fat daily to support the animal. To this he adds .054 pound of protein and .29 pound of carbohydrates and fat for each pound of milk produced containing 4 per cent of butter-fat. He recommends increasing the food of this mature animal with its special kind of work very nearly at the same rate as its weight and its product increase. This shows that different kinds of animals require different care in feeding. The good farmer must, indeed, be one of the wisest of men.

Influence of Food. Like the plant, the animal body grows to its final chemical composition quite independent of influence by the composition of its food. Experiments have been carried out in which young animals as nearly alike as they could be chosen were fed in some cases upon narrow nutritive ratios and in other cases upon wide ones. These experiments have shown that narrow rations produce somewhat more rapid growth and larger organs than do wide ones. The chemical composition of the body, however, is regulated by inheritance. Even environment does not control the animal by the power which we have learned it has to mold the composition of the plant. The composition remains the same for a given kind of animal, whatever be the nature of its food.

Condimental feeding stuffs are materials advertised upon the market with all sorts of wonderful claims. Some are recommended as tonics and others as special fattening foods. They are usually made from some common mill product such as wheat middlings or linseed meal. Common, inexpensive tonic substances like ferrous sulphate and such laxatives as sodium sulphate or magnesium sulphate are added. Those prepared for poultry generally contain ground oyster-shell or bone to furnish calcium for eggshells. They are sometimes deceptively colored. These feeding stuffs are commonly sold in small packages at prices many times their true values. The farmer should realize that their simple ingredients are sold at unreasonable prices.

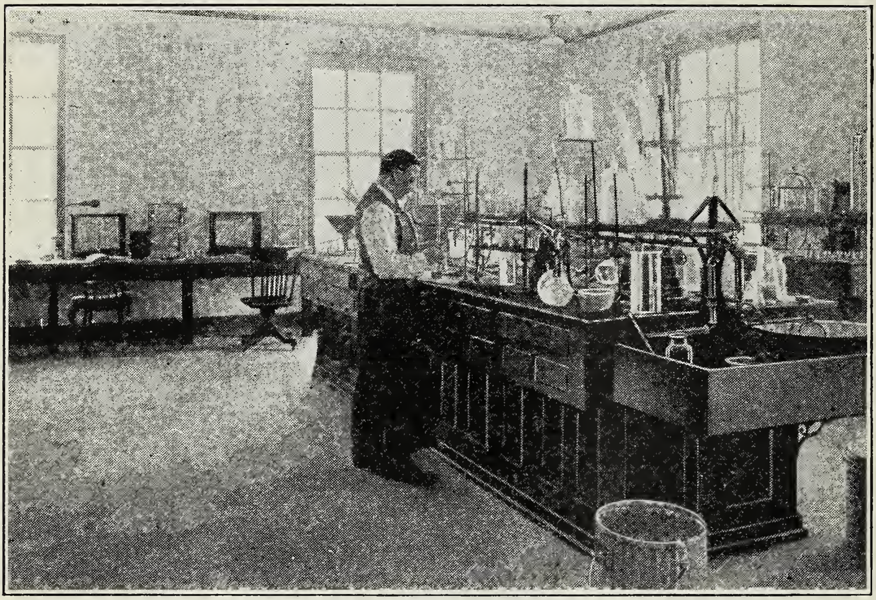


Figure 87. A chemical laboratory of a state experiment station. Here the values of commercial feeding stuffs are determined. Commercial fertilizers are also inspected here. This work protects the farmers who purchase these materials.

He should also realize that tonics cannot increase the work done by healthy, well-fed animals. If live stock need medical treatment, it is cheaper and safer to consult a veterinarian than to experiment with condimental feeding stuffs.

Feeding Stuff Laws. Purchase of feeding stuffs of all sorts is made safe for the farmer by the protection of the law. The experiment station is responsible for enforcing the feeding stuff laws. Manufacturers are required to label their goods plainly with a guarantee of their composition and Experiment Station agents are empowered to sample and analyze the products exposed for sale. Violators of the law are prosecuted and only trustworthy brands are allowed to remain on the market. This protective legislation and the results of the feeding stuff inspection published in bulletins of the Experiment Station protect the farmer in getting what he pays for.

SUMMARY

Knowledge of the composition of feeding stuffs and how they serve the animal is the basis of scientific feeding. Protein compounds, most abundant in grains and in hays of legume plants, serve for growth and repair. Fats, which occur chiefly in grains, and digestible carbohydrates, abundant in grains, are either used as fuel or stored as fat. By means of the bomb calorimeter the fats have been found to contain 2.4 times as much fuel value as the carbohydrates. This fuel value is measured in units called Calories and therms.

Only part of the fuel value of feeding stuffs is finally of use to the animal. This result is due to losses during digestion. Crude fiber, a mixture of cellulose compounds, which amounts to nearly one third of the material in some hays, is largely responsible for these losses. As a result, the producing value ranges from 0.4 of the total fuel value in some grains and mill products to only 0.06 of the total in some straws. The importance of grain to milch cows, growing animals and working horses is thus explained.

The present scientific standard for comparing feeding stuffs balances the digestible proteins against the digestible carbohydrates and fats in an expression called the nutritive ratio. The nutritive ratio should vary from narrow, or about 1:5 for young animals and milch cows to wide, or about 1:12 for resting, mature animals.

The amounts of protein compounds and fuel value increase rapidly as the muscular work of the animal increases. The need for them in growth does not increase nearly as rapidly as the size of the animal. By inclosing the animal in a respiration calorimeter his fuel need can be measured. On account of the greater proportion of surface to weight this need is greater for small than for large animals. The composition of the feeding stuffs influences the rate and amount of growth but not the composition of the animal.

In the purchase of feeding stuffs the farmer has the help and guidance of the Experiment Station, which executes state laws controlling the sale of these things.

QUESTIONS

1. Under what six groups does the chemist class the compounds of feeding stuffs by analysis?
2. How much water is there in a fresh turnip? In cured hay?
3. How much protein is there in mangels? In clover hay?
4. What is the difference between the ether extract of grains and that of hays?
5. What is the nature of crude fiber? How much in hays?
6. What is the chief compound of the nitrogen free extract of grains?
7. How much ash is there in feeding stuffs?
8. Of what use is protein to the animal?
9. For what are carbohydrates and fats used?
10. For what purpose is the bomb calorimeter used?
11. What is a calorie?
12. Which are the more efficient in supplying energy to the body, carbohydrates or fats? Why?
13. Name two materials in which unused fuel value of the food leaves the animal body.
14. What is meant by the "productive fuel value" of feeding stuffs?
15. Which has the greater productive value, cornmeal or timothy hay? Why?
16. What is the nutritive ratio?
17. When is the nutritive ratio narrow? For what animals is such a ratio desirable?
18. Will animals of like kind and size necessarily have like food requirements? Why?
19. What relation is there between the composition of the milk and the growth of the young of different species?
20. Why does the young animal require a narrow nutritive ratio?
21. What is the danger from feeding young pigs too exclusively on corn? What feeding stuffs will correct the trouble?
22. Why does the small animal require more fuel value than the large one in proportion to body weight?
23. What is the effect of rate of work on the food requirement?
24. Which increases the more rapidly, protein or fuel need?
25. What are the objections to condimental feeding stuffs?
26. What are the benefits of the state laws regarding feeding stuffs?

CHAPTER XII

DAIRY PRODUCTS

Importance of Dairying. There are three C's important in dairy farming. Have you ever heard of them? They occur in these three words: Clover—Corn—Cows. Wherever clover hay and ensilage corn thrive you may expect to find prosperous farmers. Having already studied the first two of these C's we can concentrate our attention upon the milch cow and her products.

The amount of dairy farming in the United States has increased rapidly in recent years. This is partly due, of course, to the enlarging food needs of our rapidly increasing population. At present, the yearly value of dairy products for a single state, Wisconsin, exceeds the huge sum of $100,000,000. In the manufacture of the various products from milk very complex physical and chemical changes occur. To put out these products from day to day always of high quality requires no small skill of the dairyman. He must properly control the conditions which influence these complex changes. Knowledge of chemical principles can help him greatly. As possible future dairymen we shall now consider the most important physical and chemical processes related to the handling of milk and its products.

The Udder. Milk is the fluid produced for feeding the young by special organs of the mother among that class of animals known as mammals. The milk glands of the cow, called the udder, have been developed to great capacity by man through selective breeding. Have you seen the equal of the udder of the cow shown in Figure 88? When the calf has been born, and no longer receives food directly from the mother's blood stream, the blood is turned in great currents through the blood vessels of the udder. By their peculiar and wonderful powers the cells of this organ draw upon the one side from the compounds of the blood and secrete upon the other side the valuable food fluid called milk. The water and salts of the blood are used in this process pretty much unchanged. The organic compounds of the blood, however, are rapidly rebuilt to quite different compounds which appear in the milk. Figure 89 shows how thickly masses of these cells fill the upper part of the udder. Even here, however, there are minute spaces between many of the cells, which can be seen under the microscope. These spaces join to form larger and larger cavities which finally empty into the cistern above the teat.

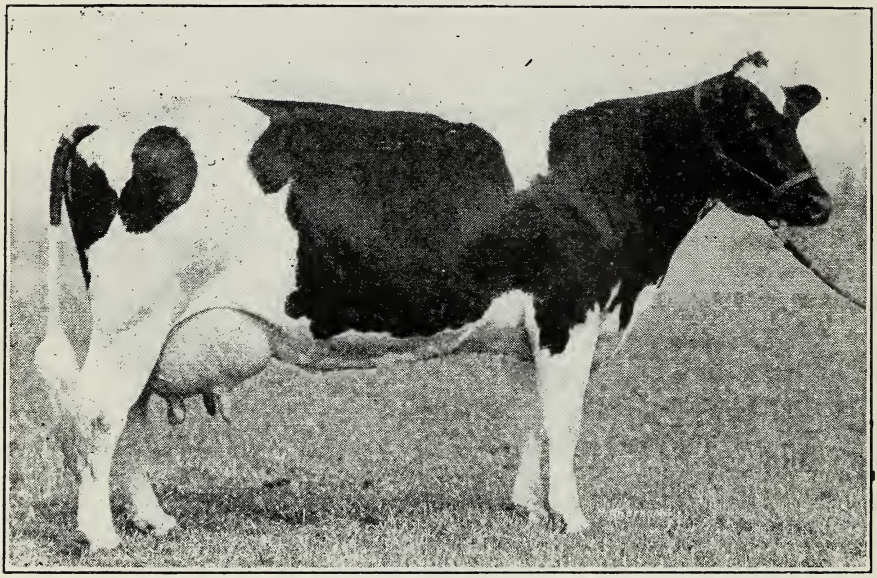


Figure 88. Friderne Pride Johanna Rue, world's champion of 1914. Besides being an animal of sensitive temperament she is a wonderful machine that produced 1,146.47 lbs. of butter-fat in one year.

Specific Gravity of Milk. Milk weighs a little more than water on account of some of the compounds which it contains. While water weighs 1,000 grams to the liter milk weighs 1,031 grams. In other words, average milk is 1.031 times as heavy as water. Learn from some help the meaning of specific gravity. The specific gravity of milk is very nearly 1.031 on the average. There is an instrument called the lactometer which shows by the depth to which it sinks whether the milk has been skimmed or watered. With whole milk this instrument sinks to a marked point on its scale. The removal of fat, the lightest constituent of the milk, by skimming increases the weight of the milk. Will the lactometer sink more or less than in unskimmed milk? If water weighs less than milk how will watering of the milk affect the depth to which the lactometer sinks? The lactometer cannot give any protection against fraud so certain as that of chemical analysis.

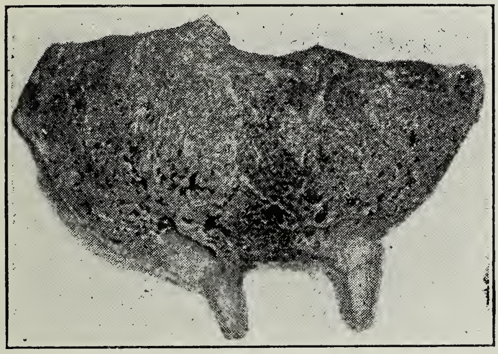


Figure 89. Section through a cow's udder.

The opacity of milk and its whiteness are due to particles suspended in it which reflect the light.

The chemical composition of milk is far from simple. In simplest terms, however, we may say that it consists of a mixture of true solution, colloidal solution and emulsion. From this we see that water is very important in the composition of milk. Water forms about 87 per cent of the material in milk. It is readily driven off at the temperature of boiling water. The remaining solid matter is called "total solids" by the analyst.

Lactose, a sugar, forms about 5 per cent of the milk or 0.4 of the total solids. This sugar belongs to the same group of carbohydrates as sucrose and maltose. It is found only in milk. Right here the remarkable power of the udder cells is shown. They receive dextrose as the only sugar in the blood and produce this quite different compound, lactose, in the milk. Lactose is quite soluble in water, but not very sweet.

Fat follows sugar in abundance in the milk. It forms about 4 per cent of the milk or 0.3 of the solids. Its amount is quite different, however, for different breeds of cows. The other constituents do not show nearly so great differences. Some animals produce milk very rich in fat. Elephant milk contains about 20 per cent and the milk of the porpoise and whale 40 to 50 per cent. Figure 91 shows that under a microscope the fat can be seen scattered in droplets throughout the milk. This suspended condition of matter is called an *emulsion.*

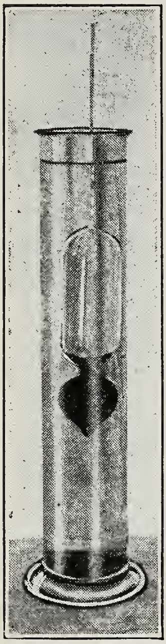


Figure 90. The lactometer in use. It is floating in a salt solution of the same specific gravity as milk.

Milk fat is not a single compound but a mixture of several different fats. A number of different fatty acids are united with glycerine in these fats. On the one hand are the acids with large molecules, such as oleic, which we studied in connection with the plant and the animal. On the other hand are fatty acids with molecules only one fourth as large as this. These acids are volatile liquids with peculiar, sharp odors, like the acetic acid of vinegar. When the butter becomes rancid, these acids are set free and produce a disagreeable odor. They are important in distinguishing butter from oleomargarine. One of the most abundant of these acids is called butyric acid Olein, which is liquid at common temperature, forms about one third of milk fat. Over one half of the fat is made up by individual fats which are solid at common temperatures. Myristin and palmitin are the chief of these. The remaining liquid fats, containing the volatile fatty acids, form about one tenth of the fat.

Upon the ratio of solid to liquid fats depends the melting point of the milk fat or butter. How will the rise and fall of the amount of olein affect the melting point of the butter?

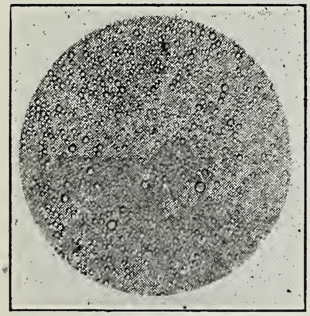


Figure 91. Fat globules as seen in a thin layer of milk under the microscope.

Proteins rank third in order of abundance among the compounds of milk. They form about 3.3 per cent of the milk or one fourth of the total solids. Casein alone forms about four fifths of the milk proteins. This protein contains, besides carbon, hydrogen, oxygen and nitrogen, 0.8 per cent each of sulphur and phosphorus. It is not truly dissolved, but exists in the very finely divided form of a colloidal solution. When acid is added to the milk, casein separates as a curd. Rennet extract prepared from calves stomach also coagulates the casein, or, as we say, curdles the milk. The active agent of this extract is the enzyme rennin. Have you noticed the wrinkled scum which forms on the surface of boiling milk? It is casein which has been made insoluble by partly drying. Lactalbumin is another protein of milk. Only about 0.7 per cent is present in common milk. It coagulates and separates in flakes when the milk is heated to 72°C. In *colostrum,* the milk produced directly after calving, there is 12 or 13 per cent of lactalbumin. This causes the whole of the milk to clot when it is heated. There are other proteins present in very small amounts in milk, but the only one we need to remember is fibrin. This resembles blood fibrin by separating from the liquid as minute, invisible threads, which may entangle the fat globules.

Inorganic salts form most of the remainder of the solids of milk. They amount to about 0.7 per cent of the milk or one twentieth of the total solids. Among these salts the chief bases rank as follows: Potassium oxide forms one fourth, calcium oxide one fifth and sodium oxide one tenth of the milk ash. Of the acid radicles phosphorus oxide forms about one fourth and chlorine one seventh of the ash. From these values it has been found that potassium and calcium phosphates and sodium chloride are the chief salts present in milk. Traces of the iron compounds necessary for the growth of the young are not lacking. The calcium phosphate is closely associated with casein. Calcium is important in the action of rennin.

Comparison of Milk of Different Animals. It will be interesting to compare with cow's milk the composition of the milks of other animals commonly used as human food. The comparison is given in Table X.

Table X—The Composition of Some Common Milks

	Fat %	Casein %	Lactose %	Ash %
Woman.....	3.3	1.5	6.8	0.2
Cow........	3.9	2.5	5.1	0.7
Goat.......	6.5	4.3	5.0	0.7
Camel......	2.9	3.8	5.7	0.6

How do the amounts of casein and ash in woman's milk compare with those of cow's milk? What one constituent is more abundant in woman's milk than in any of the others? Notice the high percentage of fat and casein in goat's milk. In recent years this milk has been recognized as very nutritious. The figures of the table are the average values for a number of different samples. We should find them considerably greater or less for different animals.

Comparison of Milk of Different Breeds. Cows have different compositions of the milk for different breeds. Only the fat and casein, however, differ much in the different breeds. For some of the more common dairy breeds the average percentages of fat and of casein are as follows:

Holstein, casein, 2.2 and fat 3.3; Ayrshire, casein, 2.5 and fat 3.8; Guernsey, casein, 2.9 and fat 5.4; Jersey, casein, 3.0 and fat 5.8. You will see that fat and casein increase together in passing from the Holsteins to the Jerseys. Divide the fat of the Jersey milk by that of the Holstein. Do the same with the casein. Which differs most widely in the two milks? We should remember that richer milk does not necessarily stamp the Jersey cow as superior to the Holstein. The latter may produce so much larger flow than the former as to yield even more of the valuable milk solids.

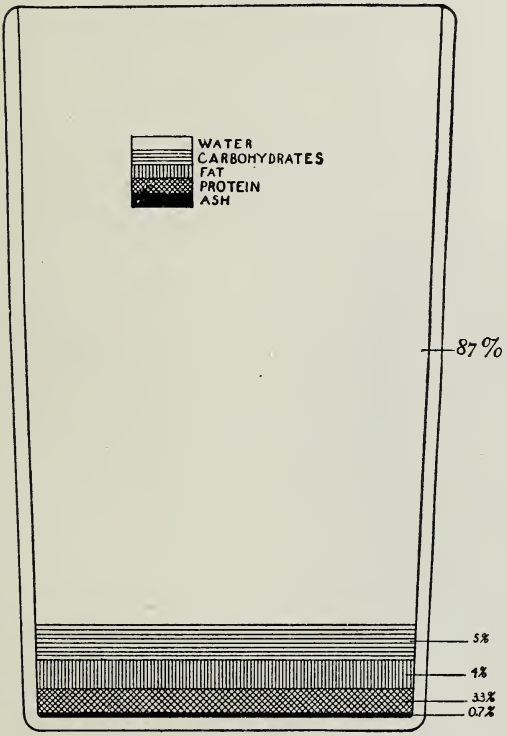


Figure 92. Composition of whole milk.

Influence of Lactation Period. The milk of any one cow varies in composition at different times. This is due chiefly to two causes: (1) the length of time she has been in milk; and (2) the kind of feeding stuffs she receives. The length of time after calving is called the "lactation period." About ten days after calving the colostrum changes to milk. During about the second month of lactation the milk becomes a little poorer in fat and other solids than at first. Then it gradually increases in richness and after four months of lactation its composition becomes richer than at first. After that it continues to increase slowly in richness. This richness of the milk at late stages of milking is due to the fact that it becomes more concentrated in total solids. No one constituent increases alone; but fat, casein and the other solids increase together and equally. What is really happening is that less water is being secreted into the milk. Have you not observed that the "flow" or volume of milk does decrease as the period of milking increases and the cow approaches dryness?

Influence of Feeding Stuffs. The amount of feeding stuffs received has no effect on the composition of the milk of well-fed cows. If the animals are poorly fed, however, they cannot do their best work in milk-making. They will produce richer milk when well fed. Sudden changes of ration also affect the composition of the milk. Cows fed on feeding stuffs containing only a moderate amount of fat will produce milk containing more fat, if a ration richer in fat is fed to them. A change to pasture grass from winter feeding acts in this way, and farmers are glad to see summer pasturing come around. These changes are temporary, however. Milk and seeds are much alike in this respect, that the cow and the plant try always to put out a product of uniform composition. So, each cow's milk soon returns to a composition natural for her after any sudden changes of her rations.

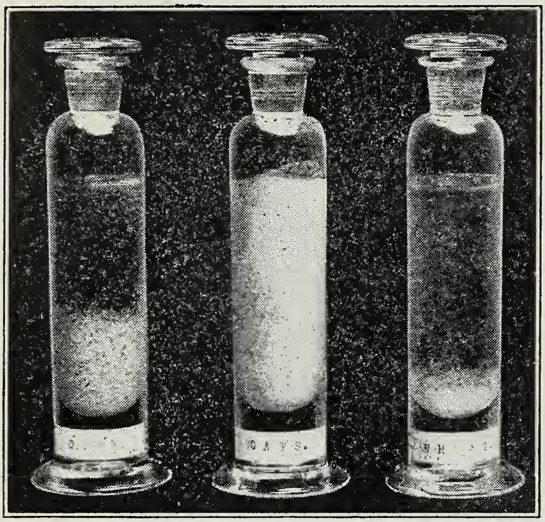


Figure 93. Showing the effect of fat from different plants upon the hardness of butter-fat.

The composition of the fat in milk can be changed by changing the feeding stuff. Corn oil and feeding stuffs rich in it, such as gluten feed, produce soft fat in the milk. On the other hand cottonseed meal produces hard fat, which is solid at ordinary room temperatures. Can you not see the importance of this property of feeding stuffs in buttermaking? The feeding stuffs act in this way by affecting the ratio of solid to liquid fats which enter the composition of the milk fat.

The Gases of Milk. Milk always contains gases. There are about 85 c.c. of gases in one liter of freshly drawn milk; that is, the separated gases would equal about one twelfth the volume of the milk. Carbon dioxide forms nine tenths of this volume of gases. When the milk stands in open pails much of this carbon dioxide escapes rapidly to the air and is replaced by oxygen and nitrogen. What really happens is a balancing of gases between the air and the milk. Any odorous gaseous substances in the air also enter the milk. Such odorous compounds escape from manure and from turnips and other vegetables. To avoid a bad flavor from these substances the milk should be removed from the stable to the milk room as soon as it is drawn.

Decomposition of milk takes place very readily. This is because its soluble organic compounds are excellent food for bacteria. These organisms are always floating in the air and are sure to get into the milk. If the milk is kept cold in a refrigerator, they act only very slowly. At summer heat, however, they multiply rapidly and soon spoil the milk. The lactic acid bacteria are the most active of these organisms. They obtain energy for life and growth by splitting lactose. From one molecule of the sugar they produce four molecules of lactic acid. When 0.6 or 0.7 per cent of this acid has accumulated, it causes the casein to coagulate. As we say, "it curdles" or "clabbers" the milk. It generally does not increase to more than about 1.0 per cent of the milk. This amount clogs the machinery of chemical reactions by which the bacteria act. From what has been said you can see the importance of cooling the fresh milk quickly, if it is to be kept sweet for a while. There are special pieces of dairy machinery for cooling by means of running water. Milk can also be kept sweet by pasteurization. This process is named from the great French biologist Pasteur, who discovered the nature and importance of bacteria. By heating the milk thirty minutes at 70°C. or 158°F. the bacteria are killed. The vessel must then be sealed to prevent entrance of more live bacteria. Unscrupulous persons have sometimes used chemical preservatives to keep milk sweet and wholesome in appearance. Borax, formalin and other substances have been used for the purpose. In the amounts necessary for effectiveness such substances are positively dangerous to the health of the public. The use of most of them is now prohibited by law.

Condensed milk and milk powder are forms in which milk is prepared both to improve its keeping qualities and to decrease the expense of shipping it. The first of these products is made by evaporating the milk in a partial vacuum. How does the vacuum affect the usual boiling temperature? It prevents browning the lactose by overheating it. Sometimes sucrose is added as a preservative. Milk powder is formed by spraying milk either upon hot steel rollers or into a chamber of hot air. In this way it is converted to a flaky powder. As fat prevents the ready evaporation of the water, it is necessary to partly skim the milk before it can be well dried. For this reason the ratio of fat to the other solids may be lower in milk powder than in whole milk.

Cream consists chiefly of milk fat together with small amounts of milk proteins, lactose and salts. It separates from standing milk by the process known as creaming. Twenty-five years ago it was still common practice among New England farmers to expose the milk in shallow tin pans at about 15.5°C. to allow the cream to "rise." This process required one to one and one half days. The cream was then skimmed off with a shallow, perforated ladle. One fifth of the fat was left behind in the process. This made valuable skimmed milk, but cut into the profits of butter-making. The milk often soured and suffered other decompositions during creaming so that the flavor and quality of the butter were injured.

The deep-setting system was developed about the year 1885. It was commonly known as the Cooley creamery system. In this system the milk is cooled quickly in deep cans by placing in ice water. Creaming goes on much more rapidly than in the shallow-setting method just described. It is nearly complete in about twelve hours, when the skim milk can be drawn away from the cream. Only one tenth to one twentieth of the total fat is left in the skimmed milk. The latter remains sweet and valuable for feeding. The best reason given for the more rapid rise of cream in the deep-setting method than in the shallow-setting method is that chilling prevents the formation of fibrin threads. It is believed that in the warm milk fibrin threads form which entangle the fat globules and hinder their rise.

Relation of Fat Globules to the Rate of Creaming. If you have an opportunity, you will find it interesting to compare the rate at which cream forms on the milk of Jersey and of Holstein cows. Place the two milks in tall glass jars side by side. The reason for the more rapid rise in the milk of Jersey cows is that its fat globules are larger than those of the other milk. Now, as your study of geometry will teach you, when the size of a sphere is increased, its surface increases much less rapidly than its volume. There is less surface, therefore, in proportion to size in the fat globules of milk of Jersey cows than in those of Holstein cows. This smaller surface offers less resistance to the milk as the buoyancy of the globules tends to raise them to the surface. Hence the larger globules cream more quickly.

The centrifugal method has now almost wholly replaced the setting or gravity methods of creaming. In this method the milk is warmed and whirled in a heavy bowl rotating several thousand times per minute. This treatment acts like the whirling of a sling. The heaviest parts go to the outside and the lighter parts, like leaves in a whirlpool, go to the center. This machine used for the centrifugal method is called a cream separator. In its rapidly turning bowl the heavier skimmed milk is thrown toward the rim while the lighter cream gathers at the center. The two then run off by separate spouts. It is possible to regulate the flow of cream to thick or thin. Thin cream contains from 10 to about 30 per cent of fat, while thick cream contains 30 to 50 per cent. There is no advantage in making the richest cream. In fact, cream containing 25 to 30 per cent of fat is best for churning and other purposes. The separator is very efficient. Only two or three one hundredths of the total fat is left in the skimmed milk. When the cream is made in any of the ways already described it contains small amounts of sugar, proteins and salts

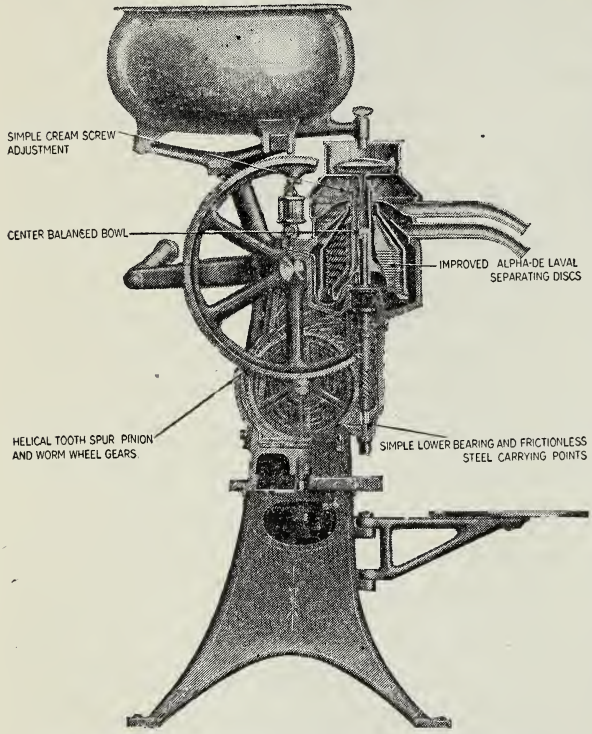


Figure 93. A cream separator. It separates the heavier constituents of milk from the fat by centrifugal force. Cream rises from the center of the bowl; skimmilk, from its circumference. —Courtesy of the De Laval Separator Co.

removed from the milk. The sugar and proteins undergo useful chemical changes in the process of cream ripening.

Butter is made by agitating cream very thoroughly. This causes the separate globules to fuse gradually into small masses. The process goes on best at temperatures from 50° to 60°F. This is brought about only with great difficulty in fresh cream. For proper churning to butter the cream must be soured. It was once the custom to leave the cream in a moderately warm place until the lactic acid bacteria finally produced the necessary amount of lactic acid and ripeness. Along with this desirable change other fermentations unfavorable to the flavor of the butter sometimes occurred. It was not possible to maintain that uniformity of quality so desirable in the marketed product. It is now general practice to pasteurize the cream, and then add starter. Pasteurizing or heating at about 160°F. kills nearly all bacteria. The starter is a pure culture of lactic acid bacteria, which act very rapidly in the pasteurized cream. In this ripening process there are slight decomposition changes of the fat and protein which contribute to the flavor of the butter.

Churning should cease while the butter fat is still in a granular condition. It can then be treated thoroughly in the washing process. This is the process in which the remaining fluid, or buttermilk, is washed away from the fat. It should be thorough, so that harmful decomposition changes may not continue in the butter. Next, salt is worked into the butter to impart a desirable flavor. If this salt and the water which remains in the butter are not thoroughly mixed with the fat, an undesirable, mottled appearance is likely to develop.

Rancidity. Exposure of butter to the air and light for a long time develops a sharp smell and taste. The butter is said to become rancid. This is due to the setting free of small amounts of volatile fatty acids. Rancid butter is improved by melting it and forcing air through it. It is then churned with sweet milk. The product is marketed as "renovated" or "process" butter.

Oleomargarine is a butter substitute manufactured from beef fat or tallow. The liquid fats are pressed from the solid fats at summer heat and then churned with various other fats. The product is salted and worked like butter. It is sometimes called butterine. When colored in imitation of butter a tax of 10c. a pound is charged on this product by the United States government. Uncolored oleomargarine is taxed ½ cent a pound.

Overrun. In making butter from milk there is a gain of water, salt and casein of about one sixth of a pound for each pound of fat in the milk. In other words, one pound of butter-fat should make one and one sixth pounds of butter. The amount of salt added is about one ounce per pound of butter. The water generally amounts to 10 to 12 per cent of the butter. It can be made nearly twice as great and sometimes is fraudulently made so. By national law, however, it is limited to 16 per cent. The increased weight of butter over the butter fat is called "overrun."

Buttermilk has considerable food value. By heating it for about two hours at 76°F. and then raising the temperature to 140°F. the casein and albumin can be caused to separate in granules. This product is salted and pressed to form buttermilk cheese.

Cheese is commonly made from milk by the action of rennet extract. This extract is prepared by soaking the fourth stomach of young calves in salt solution. The milk is ripened until 0.2 or 0.3 per cent of acid, calculated as lactic acid, is present. This process is hastened by using a starter composed of sour milk or a culture of lactic acid bacteria. The milk is then warmed to about 83°F. and rennet added. This causes the casein to coagulate and form a curd by the action of the enzyme rennin. Most of the fat is entangled and held by the curd. Afterwards the firm curd is cut into cubes by a special knife with several parallel blades. Then it is heated to 100°F. This is about the best temperature for the action of rennin. At low temperature it acts slowly and at 130°F. its power is destroyed. By keeping the cheese vat at 100°F. for one to two hours the curd shrinks. The whey is then drawn off and the curd pulls together. Finally, it is ground, salted and pressed in molds. It is then "cured" at temperatures somewhat lower than those of living rooms. Here bacteria and molds produce various changes. By the decomposition of the casein and fat compounds are produced which give flavor to the cheese. Gases which are set free also give porosity and texture to the product. Cheese made from ill kept milk often contains bacteria which produce too great porosity of the cheese and render it unmarketable. Molds are important in the development of those peculiar flavors so much liked in Roquefort and other soft cheeses. The chemical changes of cheese ripening result in the disappearance of lactose and the conversion of one third or more of the proteins to soluble compounds. The fat also partly breaks down and fatty acids are set free. Among the products

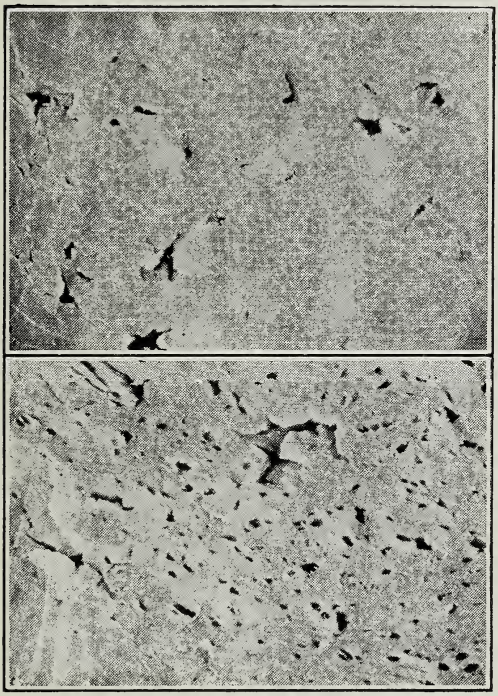


Figure 94. Good and bad cheese texture. The cheese at the top was made from clean milk. That at the bottom was made from dirty milk.

of these changes are esters, of which you will learn in studying human foods. These compounds are important in producing flavors.

COMPOSITION OF DAIRY PRODUCTS.

In Table XI are given the average composition of butter and cheese and their by-products.

Table XI—The Average Composition of Some Dairy Products

	Water %	Fat %	Protein %	Sugar or lactic acid, etc. %	Ash %
Butter	11.5	83.0	2.1	0.0	3.4
Buttermilk	91.0	0.5	3.5	4.3	0.7
Cheddar cheese	34.5	32.5	26.5	3.0	3.5
Whey	93.3	0.3	0.9	4.9	0.6

Babcock and Hart Tests. This table shows the great importance of fat in butter-making and of fat and protein in cheese-making. It is very important, you see then, to be able to determine these constituents quickly in milk. They are the substances to be paid for in purchasing the milk. The standard chemical methods for determining these constituents require considerable time. On this account there have been developed rapid mechanical methods for separating and measuring them. These are the well known Babcock fat test and the newer casein test developed by Professor Hart of the Wisconsin Experiment Station. Figure 95 shows the appearance of the completed tests. In the Babcock test the casein is dissolved by strong sul-

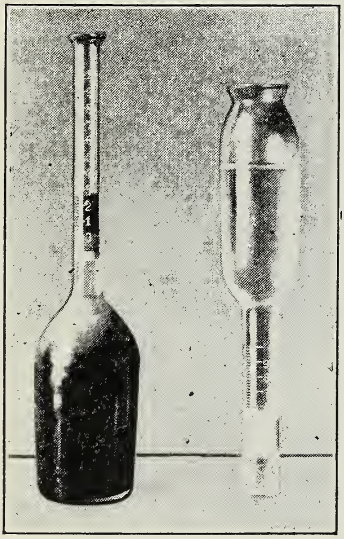


Figure 95. Finished Babcock test for fat (left) and Hart test for casein (right).

phuric acid. The liquid fat is then separated by centrifugal force in a warmed, rapidly rotating machine. In the Hart test the fat is dissolved by chloroform. The casein is then coagulated by weak acetic acid and separated in a compact column by a centrifugal force of definite strength. These tests are of much value, as they can be rapidly performed at the creamery or cheese factory.

Butter and Cheese Flavors. In grading or scoring butter and cheese upon the market nearly one half of the weight of the scorer's rating is thrown upon the single quality of flavor. This is a quality in the measurement of which chemistry is as yet of little service. Good and poor cheeses or butters may give the same results to ordinary chemical analysis. The flavoring constituents of these dairy products are present in so small amounts as to baffle for a long time attempts to determine them in a chemical way. Like musk and the odorous compounds of many flowers, they may be so powerful in their action upon the nerves of taste and smell that mere traces determine the quality of the butter or cheese.

SUMMARY

The development of dairying is widening rapidly. Its products are of great total value. These conditions make it especially important for the dairyman to put upon the market products uniformly of high quality. To attain this end he must know the chemical principles with which he deals and the influence of different conditions upon them.

Milk is secreted from blood by special cells of the body. It consists largely of water in which are dissolved a sugar called lactose, proteins and salts. A protein called casein is distributed through it in the finely divided form of colloidal solution. A mixture of fats is suspended in it in minute droplets which form as emulsion. The phosphates of potassium and calcium and sodium chloride are the chief salts present.

Fat varies much more in amount than any of the other compounds of milk. Some breeds of cows, such as Jerseys, produce milk especially rich in fat. The amount of fat in milk can be increased, but only temporarily, by increasing the fat in the rations fed. The composition of the milk fat can be permanently affected by the kind of fat in the feeding stuff. In this way hard and soft butters are produced.

Considerable carbon dioxide is present in freshly drawn milk. It escapes rapidly and is replaced by the gases of the air and such odorous substances as may be present. This necessitates guarding the milk from absorbing undesirable odors.

Milk is very prone to decomposition by bacteria, chief of which are those producing lactic acid from lactose. Cooling the milk checks these bacteria and pasteurizing kills them. Condensed milk and milk powder are forms to which milk is converted for improving its keeping qualities and cheapening cartage. The use of chemical preservatives, which both encourage unsanitary conditions in the dairy and endanger the health of the public, should be prohibited.

Cream consists of the milk fat as separated by gravity or the cream separator, together with water and other milk compounds. Large fat globules cream more readily than small ones. The separator is much more efficient than gravity in creaming.

Butter, the gathered fat from cream, requires for its preparation attention to the ripeness, or sourness, of the cream and its temperature. It must be thoroughly washed and worked to insure good keeping quality and uniform texture and appearance. Rancidity, or sourness, develops in butter by excessive exposure to air and light. Oleomargarine is a butter substitute made from the softer parts of tallow.

Cheese consists of the curdled casein of milk and fat and other compounds removed with it. As it ripens the compounds become more soluble and partly disappear. Gases which are produced give it a porous texture. Other compounds produced give various prized flavors.

The Babcock fat test and Hart casein test provide means for quickly determining the value of milk for butter and cheese making. The ingredients of these dairy products which produce that most important quality termed flavor have so far pretty much escaped the grasp of the analytical chemist.

QUESTIONS

1. From what body fluid is milk produced?
2. For what purpose is the lactometer used?
3. Why is milk heavier than water?
4. What per cent of solid matter does whole milk contain?
5. What is lactose?
6. Which constituent of milk solids varies most in amount?
7. How does milk fat differ from the fat of oleomargarine in composition?
8. What is the chief protein of milk?
9. Name three bases and two acids abundant in milk ash.

10. What two constituents of woman's milk are deficient as compared with cow's milk?

11. What are the two factors chiefly influencing the compostion of cow's milk?

12. How do feeding stuffs affect the melting point of butter-fat?

13. Why should milk be removed from the stable as soon as drawn?

14. What causes the souring of milk?

15. Why is the use of preservatives objectionable?

16. How are condensed milk and milk powder prepared?

17. Why does the milk of Jersey cows cream more rapidly than that of Holsteins?

18. How is the improvement of creaming by cooling the milk explained?

19. Upon what principle is the cream separator based?

20. What is the action of the churn in butter-making?

21. What chief advantage is secured by pasteurizing the cream and using starter before churning?

22. Why is thorough working of the butter important?

23. What is the cause of rancid butter?

24. What is the overrun?

25. To what value is it limited by law?

26. What is rennin?

27. What chemical changes occur in the curing of cheese?

28. What is the service of the Babcock test to the dairy industry? The Hart test?

29. Can quality of cheese or butter be measured chemically?

CHAPTER XIII

HUMAN FOOD AND DIETETICS

Man's Dietetic Needs. Food includes all substances whose compounds either supply energy to the animal body or promote growth, or do both, without harmful effect. One might consider scientific feeding to be the same for human beings as for farm animals. They are closely akin. The processes of digestion are essentially the same in man and live stock. By a little study you will be able to make quite a list of foods which the two eat in common. On the other hand, we can find differences which give to the feeding of man great importance as a special subject for study.

Dietetics presents the kinds and forms of food with the principles governing their use.

In order to make the importance of this subject clearer, let us try to answer the following questions:

First: How are human foods, in contrast to animal foods, generally treated before serving? Is this treatment likely to have any effect upon the composition and digestibility of food stuffs?

Second: Which has the more varied activities, man or the common animals? Will these differences of activity require any differences of attention to food values?

Third: Has man or the common animals the more cultivated sense of taste? What special factor in the preparation of meals is magnified by this difference?

Is it not now clear that dietetics, or the scientific balancing of human food rations, requires even more frequent and closer attention than the feeding of animals?

The practice of dietetics requires a knowledge of the composition and fuel value, or energy-supplying power, of foods. We shall take up these subjects in succeeding paragraphs. The several organic compounds which will need consideration have become familiar already in our study of "The Plant and Its Products." We have previously also learned about the processes of digestion, nutritive ratio and fuel value of foods in our study of "The Animal and Its Products." Hence it is unnecessary to consider these topics at this place.

Fuel Needs of the Human Body. The methods of measuring the food requirements of man and the efficiency of his foods have been highly developed. Figure 81 shows the respiration chamber or calorimeter and its accessory apparatus with which such studies have been conducted with cattle. By similar nutrition experiments it has been found that the fuel requirements of a middle-aged man of average size, or of 150 pounds weight, is about 65 calories an hour when he is asleep. This is equal to the heat produced by the complete burning of 16 grams of sucrose. If you calculate this value in avoirdupois units, you will find it to be a moderate quantity. Would you expect the fuel requirements to be changed much by awaking, but remaining at rest? The fuel value of the food necessary for this state is called the maintenance requirement. It will be well to write a definition for it in your own words. Strange to say, this requirement amounts to about 100 calories, or much more than the sleep requirement. The energy requirement of man is put to several uses, roughly as follows:

Digestion processes	10 per cent
Circulation of blood	8 per cent
Respiration	15 per cent
Muscular tension or "tone"	40 per cent
Other purposes	27 per cent

Note which of these factors consumes the most fuel value. It is to this that the increased requirement of wakeful over sleeping hours is due. The distribution of the fuel value of food for producing the energy required by the organs suggests somewhat the principle of the steam engine. How would you expect work to affect the fuel requirement? A man actively working needs about 290 calories and at very severe labor he needs 600 calories per hour. Is not this comparison sufficient to show the great importance of the fuel value of foods? Dividing the preceding fuel needs proportionately among the various ways a man lives, his total need for a day is about 3,800 calories. This value must be kept in mind in balancing foods for the table.

While the temperament of the individual, especially his muscular tension, varies greatly, woman requires generally about 0.8 as many calories as man. In addition to muscular activity, one must take into account the need of maintaining a constant body temperature of about 98° F. These two factors make the fuel requirement of children comparatively high. Besides their characteristic muscular activity they have more surface in proportion to weight than adults. They are, therefore, more subject to loss of body heat in cold weather. Children less than two years of age require 0.3 as many calories as adults. Their need increases by 0.1 the full need of man with about each three successive years of age. For equal weight of body the child of two years of age or under requires twice as much fuel value in its food as the adult. Is not this sufficient reason for the prodigious appetite of the average small boy? It is but a normal demand which must be properly satisfied.

Protein Needs of the Human Body. It was once thought that work destroyed the protein compounds of the muscle and that this change was the source of energy for work. Now, however, we know that this energy is derived from the burning of sugar in the muscle cells. This process results in greater excretion of water and carbon dioxide, instead of such waste nitrogen compounds as would result from protein. So one breathes and perspires more at work than at rest. Protein can furnish energy equal to that produced by sugar, and in case of starvation the proteins of the muscles do so. Its use in this manner is wasteful, however. Carbohydrates and fat, the latter 2.4 times as efficient as the former, are the true fuel compounds of foods. Protein owes its great value to its importance in growth and repair of the body. If you will review the composition and work of protoplasm, as given under "The Plant and Its Products," you will see good reasons for this importance. Protein is wasted by feeding too much fat, as well as by feeding too little. In the former case, the protein of the body seems to be overtaxed to digest and assimilate the fat. In the latter case, the food or body protein is used to fill the lack, if carbohydrates are also lacking.

The requirement of protein for the repair and growth of the tissues of the body is as important as the fuel requirement just described. The amount of protein in the food necessary to meet the daily needs of the average man has been placed at 60 grams. With this amount most persons neither lose nor gain protein of the body. To merely balance the protein is not enough, however. Most scientists agree that double the preceding amount should be supplied, on account of some special stimulating effects for which the body needs a liberal supply of this food constituent.

Working Men's Needs. The food requirements of men at light and heavy labor as provided for in different countries is interesting, as given in the following figures:

Table XII—Human Food Standards for Different Countries

Occupation	Country	Grams of Protein per day	Calories of fuel value per day
Business men and students. .	United States	106	3,285
	France	110	2,750
Laboring men	United States	100	3,425
	England	89	2,685
	Germany	134	3,061
	Japan	118	4,415

The average of many statistics of this sort shows that "the world over" a man receives daily about 100 grams of protein and 3,000 calories. These values are somewhat lower than high authorities recommend.

Classes of Food Stuffs. We can now consider the several classes of food stuffs in the light of man's food requirements. For the sake of convenience, let us classify foods into two groups, as follows:—

Protein supplying foods:	Energy supplying foods:
Meat and fish	Cereal grain products
Milk and eggs	Vegetables
Legume vegetables	Nuts
	Fruits

Table XIII—Food Values of Some Important Food Stuffs as Purchased

	Water per cent	Nutrients			Fuel Value
		Protein per cent	Fat per cent	Carbohydrates per cent	Calories per pound
Animal Foods					
Beef, sirloin steak	54.0	16.5	16.1	....	975
Mutton, chops	42.0	13.5	28.3	....	1,415
Pork, smoked ham	34.8	14.2	33.4	....	1,635
Poultry, fowl	47.1	13.7	12.3	....	765
Fish, dressed cod	58.5	11.1	0.2	....	220
Eggs, of hens	65.5	13.1	9.3	....	635
Milk, whole	87.0	3.3	4.0	5.0	310
Vegetable Foods					
Bread, white	35.3	9.2	1.3	53.1	1,200
Oat meal	7.7	16.7	7.3	66.2	1,800
Beans, dried	12.6	22.5	1.8	59.6	1,520
Peas, shelled	74.6	7.0	0.5	16.9	440
Potatoes	62.6	1.8	0.1	14.7	295
Tomatoes	94.3	0.9	0.4	3.9	100
Apples	63.3	0.3	0.3	10.8	190
Bananas	48.9	0.8	0.4	14.3	260
Hickory nuts	1.4	5.8	25.5	4.3	1,145
Peanuts	6.9	19.5	29.1	18.5	1,775
Cocoa, powered	4.6	21.6	28.9	37.7	2,160

Table XIII gives the food values of some important food stuffs. For more complete tables one must refer to special texts. Is water a nutrient compound in foods? Suppose all the water were removed from these materials. How would that affect the present difference of value per pound between oatmeal and potatoes, for example?

Meats, Milk, Eggs. The preceding table shows that, with the exception of milk, the animal foods do not contain appreciable amounts of carbohydrates. With the exception of eggs and fish, the animal foods supply as much, or more, fat as protein and rank well in fuel value. Fish, however, forms practically a protein food. It is well balanced by the Japanese against the high fuel value of rice.

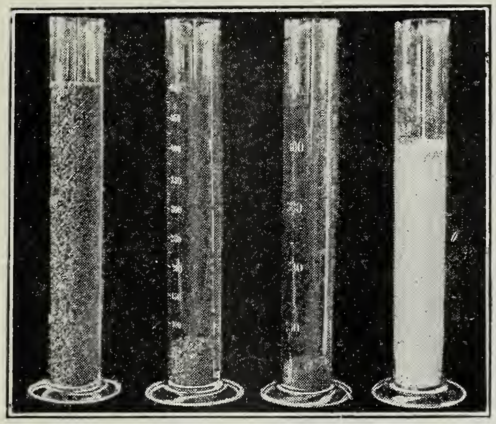


Figure 96. Wheat and its food products. The second cylinder contains the amount of bran and gluten layers present in the wheat grain of the first cylinder. The third cylinder contains the amount of germ or embryo this wheat would yield. The last cylinder contains the amount of starch cells present in the wheat of the first cylinder. In milling good, hard wheat about 70 per cent of the grain is turned out as flour, 13 per cent as bran, 6 per cent as middlings and 6 per cent as "red dog" and screenings. The latter by-products are familiar cattle feeds. They contain coating and germ cells, with some starch.

Vegetables. Among the vegetables, beans and the other legume seeds are distinctively rich in protein, yet these contain enough carbohydrates to form a large part of the fuel required by their protein for a balanced food ration. Bread and the other cereal grain products are distinctly fuel foods, due to their high content of starch. The very watery fresh vegetables and fruits have little direct food value. Besides, on account of the protecting action of their cellulose compounds, the digestive secretions act less thoroughly upon them than upon other foods. Their value lies chiefly in either laxative or flavoring effects. Some nuts have the highest value of all food stuffs, because nearly all contain much fat, besides considerable protein. The peanut is especially rich in these compounds. Such food stuffs, however, are too "heavy" to be consumed in great quantity. Hence, they must form a small, supplementary part of meals. Cocoa differs from other common beverage-forming substances by its high food value. You will find it helpful now to secure larger tables of food values and make lists of foods rich in protein and those high in fuel value.

Cereal Grains. On account of the enormous quantity of human foods supplied by the milling of wheat and other cereals, these grains deserve special study. The "bumper" crop of wheat in our country for 1914 was estimated as nine billion bushels, and this was but one fourth of the world's crop. In the milling process most of the starch of this grain, which forms 85 per cent of it, goes to produce flour. The flour, therefore, contains about 3 per cent more starch and 2 per cent less protein than the whole grain. About half of the fat and ash constituents are lost in the germ and bran, and about 80 per cent of the phosphorus of the grain is contained in the bran. This fact has led to the belief that white bread supplies insufficient phosphorus for man. This theory does not seem to be true for adults on mixed diet; but it should be carefully considered in feeding mothers and growing children. They need much phos-

Figure 98. Transplanting rice in Japan. This interesting crop provides the chief food of more than half the human race.—By courtesy of Mrs. F. H. King.

phorus for the production of milk and the growth of bones. The favorable laxative effects of whole wheat or graham breads probably are due both to their fibrous nature and to their phosphorus compounds. Bread, macaroni and other flour products owe their making to the gluten of the grain. This is a mixture of two proteins. One of them, gliadin, is soluble in strong alcohol. The other is soluble only in alkali solution. In good bread-making wheat gluten forms about 85 per cent of all the protein. Gliadin should form about 65 per cent of the gluten. No definite percentage of protein has been found to insure good bread-making qualities of wheat. It is certain, however, that too much produces wet, "soggy" bread. On the other hand, too little produces dry bread of poor quality. Rye contains gluten with bread-making properties much inferior to that of wheat. None of the other grains possesses this valuable constituent.

Besides, in the making of bread and pastry, the cereal grains, as barley, are used for soups. You are familiar, too, with their wide use as breakfast food, either raw or cooked. The latter, as corn flakes, are prepared by slicing or shredding and toasting the grains. They are of nearly the same composition as the raw grain, except that the heating produces soluble carbohydrates, as dextrins and sugars, from the starch. These add flavor to the products. A few, as grape nuts, contain considerable sugar and salt added for this purpose. There is no appreciable difference

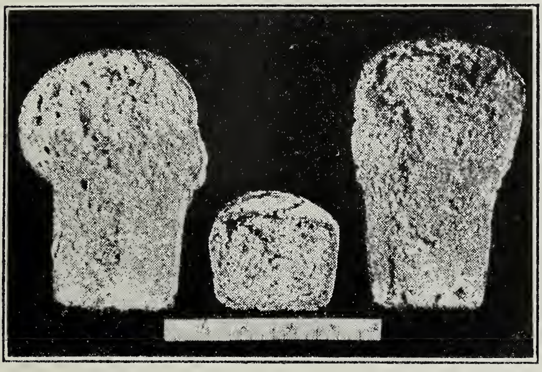


Figure 97. The relation of proteins to bread-making. The loaf on the left was made from whole flour. The middle loaf was made from flour which lacked gliadin. The right hand loaf was made from flour which had been extracted with water.

of digestibility between these products and the home-cooked breakfast foods.

Fruits. Besides their high percentage of water, fruits consist mostly of sugars and acids enclosed in the cellulose compounds which form the pulp. The hardness of green fruits is due to pectose, a substance of carbohydrate nature. Such fruits contain considerable starch also. As they ripen the pectose is changed to pectin, a soluble substance, and the starch to sucrose, dextrose and levulose. Thus the fruit mellows and acquires flavor. The latter is due chiefly to the kinds and amounts of organic acids and to traces of essential oils. The latter are neutral bodies resembling waxes in composition and of pleasing flavor and odor. Malic acid, the most common acid of fruits, forms about 1 per cent of the juice of sour apples. Tartaric acid, either free or as acid salts, forms 1 to 5 per cent of grape juice and citric acid forms about 7 per cent of lemon juice. The essential oil of the apple is ethyl acetate, a compound of common alcohol with acetic acid, the characteristic acid of vinegar. This, and related oils, such as those of the pineapple and banana, can be prepared readily in the laboratory. On account of the small amount of nutrients they contain, fruits must be given value chiefly for their laxative effects and the stimulation of appetite.

Figure 99. The yeast plant as seen under the microscope. New cells form by "budding" from the old ones.

Ciders, wines and vinegars derive their valued properties from the fermentation of sugars in the fruit juices. When the juice is "seeded" with certain low forms of plant life, the yeasts, the latter act upon the sugars and produce alcohol and carbon dioxide. Figure 99 shows the manner in which yeast grows by budding. Since these plants are ever present in the air and on fruits the juices "seed" naturally and fermentation proceeds without attention. After this process has been completed, another fungus forms acetic acid from the alcohol and produces vinegar. This fungus occurs in gelatinous masses in vinegar barrels, whence its common name "mother of vinegar." Only 2 or 3 per cent of alcohol accumulates in apple cider. Cider vinegar must contain 4 per cent or more of acetic acid to meet the requirements of the national food laws.

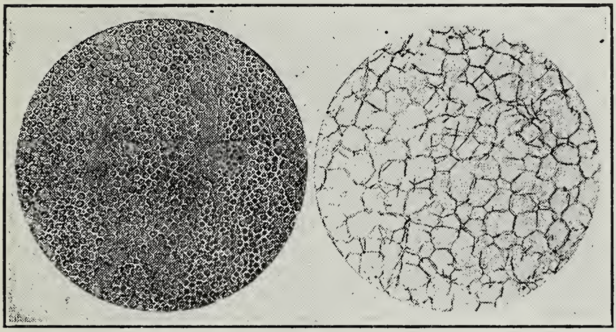
Cooking, as suggested early in our present study, may alter the composition of food stuffs. It changes the physical structure, however, much more than the chemical composition. What change have you observed in the texture of meat and vegetables as they are boiled? There are present in meat juices soluble proteins, carbohydrates and salts. These form only a small part of the whole meat, however. If the meat is boiled, something over 10 per cent of the protein and 80 per cent of the salts are extracted. These give value to the broth. It was formerly believed that plunging the meat directly into hot water formed a sort of crust of coagulated protein and reduced the loss of food compounds into the broth. It is now known that no greater loss occurs when the meat is placed in cold water and gradually raised to boiling. By dry cooking, as roasting or frying, the surface tissues are quickly closed. Meat cooked in this way retains about one half the soluble compounds of the raw flesh. It is about 2.5 times richer in these compounds than boiled meat. Any sort of cooking removes much of the water of fresh meat, while improving its texture and flavor. The total food value is little influenced, however, by any method of cooking.

In the cooking of eggs, as with other protein-rich foods, there is but a slight decrease of digestibility of the protein compounds. "Hard boiling" reduces the digestibility of the white of egg; probably because it is less thoroughly masticated and exposed to the digestive fluids of the body than is a "soft boiled" egg. The pasteurization of milk was at one time believed to seriously affect its food value. Careful study has shown, however, that it produces no appreciable changes of composition or digestibility.

Baking. The baking of bread and pastry includes the common process of lightening the dough by "raising." This produces the light, leavened bread so much superior to the heavy, unleavened material. This interesting and important process is produced chiefly by releasing carbon dioxide within the mass of dough. In escaping, this expands the dough to a light, porous mass which "sets" by baking. In bread-making, yeast is added to produce the carbon dioxide. From your previous study of fermentation what compounds would you expect it to act upon? Like other low organisms, it is well supplied with enzymes. These convert the starch of the dough to sugars, and the latter to alcohol and carbon dioxide. What effect do you remember increase of temperature to have upon the speed of chemical reactions? To a limited extent enzyme processes are affected in the same manner. So we find the rising of dough hastened by keeping it in a moderately warm place. Thirty degrees Centigrade is the best temperature. How many degrees Fahrenheit is it equivalent to? The products formed largely escape in the baking. A small amount of organic acids, chiefly the lactic acid characteristic of sour milk, is produced in the fermentation. This gives acidity and flavor to the dough and bread.

In other flour products than bread, the raising of the dough is generally accomplished by means of baking powders. These substances consist of mixtures of sodium acid carbonate with acid salts. Cream of tartar contains potassium acid tartrate. Phosphate powders contain calcium acid phosphate. Alum powder contains potassium aluminium sulphate, one of the alums, and sometimes also calcium acid phosphate. What well known gas will be released when these powders are moistened, and how is it produced? Alum powder is objectionable on account of the irritating effect of aluminium salts on the digestive organs. A good baking powder will release at least 10 per cent of its weight of carbon dioxide. Do you see why it is important that these powders be kept dry?

Baking removes a large part of the water from bread dough. It also volatilizes some of the organic acids and most of the gaseous products of fermentation already named. Part of the starch is changed to dextrins, sugars, and traces of gaseous hydrocarbons. These products give flavor and aroma to the bread. About 15 per cent of the total starch of the flour is lost in this manner.



F'gure 100. The effect of popping on the corn grain. On the left, the starch granules are greatly swelled. On the right, they have burst the cell walls and become nearly as large as the original cells of the grain.

Toasting of bread and popping of corn produce chemical changes like those just attributed to baking. Chief among these changes is the loss of water, as shown by the shrinkage and increase of brittleness in the food stuffs. The explosive escape of steam from the corn ruptures the kernel and disintegrates its cells. The dextrins, hydrocarbons, and other products formed enhance the flavor and palatability of these foods.

Cooking of Vegetables. Vegetables are especially valuable when eaten raw, as cabbage, lettuce, and tomato in salads; for in this form all the ash constituents are obtained. The former two and spinach have nutritive ratios as narrow as 1:4, whereas in most vegetables, the ratio is twice as wide. Frequently, however, not more than one half of the nitrogen compounds of these foods are proteins. In the usual methods of cooking vegetables, as stewing, or boiling, they lose one third to one half of their food value in the water. Hence they are best cooked as soups or stews. Potatoes, especially, often lose much of their nutrients, excepting starch, by soaking for a long time in cold water, when peeled. They should be baked or boiled in their "jackets," if the most value is to be obtained from them.

Have you observed how quickly some vegetables, especially the potato, and various fruits turn black upon freshly cut surfaces? This change of color is due to the oxidation of a protein-related compound by an enzyme. Changes of composition also occur in whole stored vegetables, fruit, and grains. They are such as we have found to occur in silage-making. At high temperatures, as at 30° C., respiration is rapid. From your previous study, what compounds do you think support this respiration? What products are formed? As they disappear the starch is drawn upon to replace them. This causes the tuber to soften and lose quality. At temperatures approaching freezing, on the other hand, respiration is checked, but sugar continues to accumulate slowly by enzyme action. This excessive respiration at high temperature decreases the quality of the tubers. The best temperature for the storage of potatoes is about 8°C. Considerable study has been made of the relations between cooking qualities and chemical composition of potatoes. It has been found that the factors which determine quality are too obscure to be yet determined by chemical analysis.

Spices and flavoring extracts owe their characteristics in large part to essential oils. These compounds have been described already. They serve chiefly to stimulate the flow of digestive secretions, as saliva and gastric juice, and "whet" the appetite. Do you think the amounts of these materials used appreciably increase the protein or fuel value of the food? Some are derived from fruits, as pepper, mustard, allspice, and nutmeg. Cinnamon is a tree bark and ginger is prepared from the root of a plant by that name. Cloves are the dried flower buds of a tropical evergreen tree. The active substances of pepper are a volatile oil and 5 or 6 per cent of the alkaloid piperine. Mustard owes its sharp taste to an organic sulphur compound, a close relative of the compound giving character to onions and garlic.

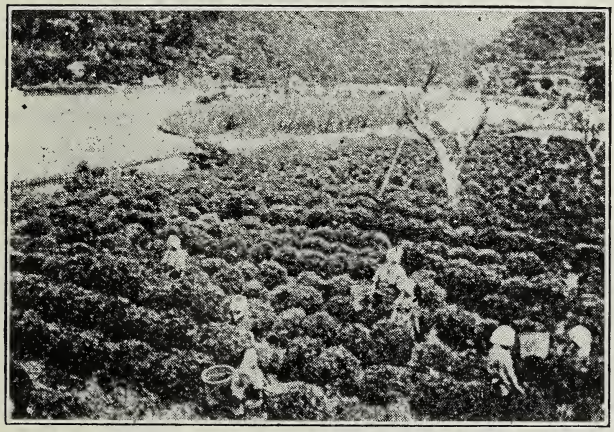


Figure 101. A tea farm in Japan.—(Courtesy of Mrs. F, H. King.)

Beverages, as tea and coffee, generally are drunk in so small amounts daily as to be of little importance as food. The two materials named have stimulating properties, due to an alkaloid, caffein, which acts on the nerves and heart. With most adult persons the effects are mild. The bitter taste of tea is due to tannin. This beverage is prepared from the leaves of an oriental shrub. The dry leaves contain about 13 per cent of tannin and 3 per cent of caffein. Green tea is produced by drying the leaves rapidly with artificial heat, and with the loss of a little tannin. Black tea is made by bruising the fresh leaves and allowing them to ferment before drying. In this treatment, they blacken, due to enzyme action. The product differs from green tea by containing only about 5 per cent of tannin. Coffee, the husked seed of a tropical evergreen tree, contains considerable fat and carbohydrate. Caffein is present to the extent of about 1 per cent. It is, therefore, a weaker stimulant than tea. By roasting, the "berry" loses most of its water, while its soluble carbohydrates increase about tenfold. Cocoa and chocolate are prepared from the pod-enveloped beans of a tropical American tree. The beans contain about 50 per cent of fat. After husking, they are allowed to ferment, which reduces their bitterness and acidity. They are then hardened and darkened by drying in the light. Chocolate is prepared by removing the germs from the beans. It has practically the same composition as the latter. Cocoa, on the other hand, is prepared from the residue of the beans left after extracting part of the fat to form cocoa butter. Its chief constituents are about 30 per cent fat and 10 per cent protein. Hence, it has a lower food value than chocolate. Still, even when made with water, it has about four times the value of tea or coffee. Cocoa and chocolate contain one to two per cent of caffein and other alkaloids.

Having compared the values of foods, we can study the principles of dietetics. The diet of common individuals and families may be considered from two chief points of view: (1) as to efficiency, and (2) as to cost.

Balancing the Diet. Economy alone, irrespective of the standard protein and fuel values, is not a safe basis upon which to plan a diet. Prolonged feeding of some single food stuff which contributes to the standard requirements may lead to ill health. Some food stuffs which appear well by these same standards may also contain poisonous ingredients. Examples of these sorts of food troubles are the prevalence of the disease beri-beri among people fed too exclusively upon polished rice, and occasional poisoning by mushrooms. These conditions require attention to what is called the physiological balance of foods. This means the balance necessary to produce good health and growth.

Acid and Base Balance. A very important balance to be adjusted in human foods is that between acid-forming elements, as sulphur, and base-forming elements, as potassium. The former are oxidized to acids by the processes of digestion and assimilation. If other bases are lacking, ammonia is withdrawn from the protein of the body to neutralize these acids and provide for their excretion. Such a process is not only wasteful, but also disturbs the health. Then, too, the mother and young growing child must have the necessary balance between calcium and phosphorus in order that they may produce calcium phosphate of the skeleton and milk. Again fatty foods, such as too rich milk, may disturb infants by the removal of calcium from the body. This is used to form soaps, in which the excess of fat is excreted.

The differences between food stuffs as to the amounts of acid-forming and base-forming elements which they contain are shown in Table XIV. The values in the first column express the excess of acid-forming over base-forming elements in portions of the material supplying 100 calories of fuel value. The second column expresses the opposite relation for the same amount of food. The figures represent cubic centimeters of standard (normal) acid or alkali solution.

Table XIV—Acid-forming and Base-forming Foods

	C. C. of standard acid in 100 calorie portion	C. C. of standard alkali in 100 calorie portion
Acid-forming Foods		
Lean Beef	10.0	....
Eggs	9.0	....
Wheat Flour	2.7	....
Base-forming Foods		
Celery	....	40.0
Potatoes	....	10.5
Milk	....	3.3
Corn	....	0.6

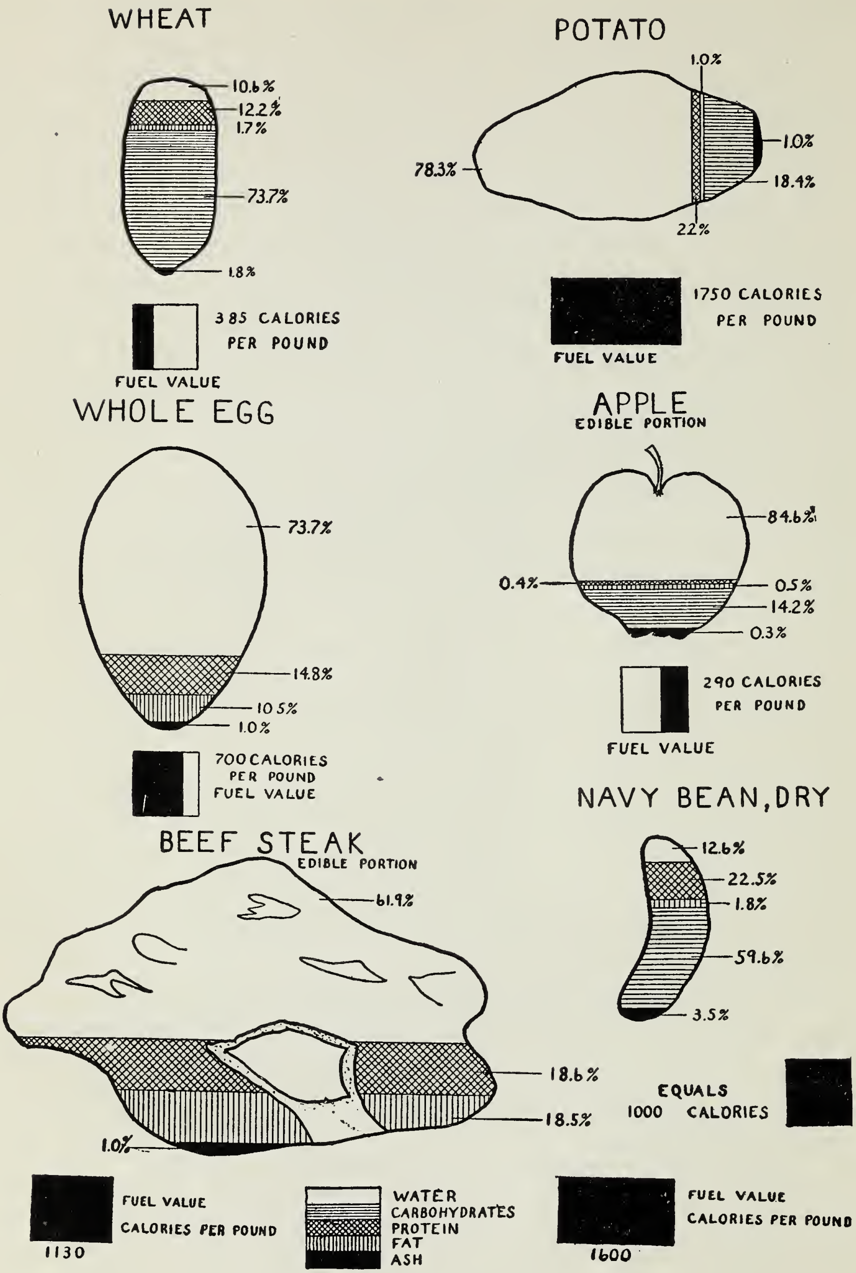


Figure 102. The food values of some important articles of human food.

Is it necessary to emphasize further the importance of varying the diet by introducing vegetables and fruits to balance meat and eggs?

Economy in Cost of Diet. A few years ago more fuel value could be obtained for ten cents in milk, beans and flour than in any other food stuffs. That situation is even more true at present. Dr. H. W. Wiley, well-known champion of pure food legislation, points to the cereal grains and their products as the sources of relief from "the high cost of living." This economic condition applies especially to the great mass of laboring population.

It is possible to economize in cost while still securing food values, as is shown by a comparison of two families made by Professor Snyder.

The chief items of expense of the first family were bread, cake and pastry, steaks and roasts, and canned goods. Among the more expensive items of the second family were steak and boiling pieces, butter and milk. This family made its bread and pastry, cooked oatmeal instead of using patented breakfast foods, and substituted homemade shortening for butter. It also substituted beans and cheese partly for meat, and ate liberally of the less expensive vegetables and fruits. A comparison of the food values and cost per week follows. It shows that the second family obtained a larger amount of nutrients at one half the expense of the first.

Table XV—Comparison of Food Values and Cost for Two Families

	Protein Pounds	Fat Pounds	Carbohydrates Pounds	Cost Dollars
Family 1	7.9	14.0	19.0	22.45
Family 2	10.6	14.8	26.4	11.30

Large amounts of concentrated food, such as cheese, should be avoided. They place too much tax upon the digestive system. One must consider the palatability of foods, as well as their economy and food values. This is especially true of the diet of invalids, who frequently require either the palatability or the ease of digestion possessed by meat extracts and similar foods. In such cases, unusual lack of economy in the purchase or use of food stuffs may be justified. With the help of the principles and tables you have now studied, it would be well to plan several menus for a man at light, and also at severe labor. You might also plan menus for your own family.

Preservation of Food. With the congestion of population in our cities, the preservation of food becomes a necessary problem. Meat must be kept fresh and edible during storage and transportation. Fruits and vegetables also must be kept available, so far as possible, throughout the year. You are familiar, probably, with the great importance of storing meats by refrigeration in the big packing industry. This does not entirely check changes due to enzymes, but it prevents the growth of bacteria, and the meat keeps in good condition for long periods. It is especially important that bacterial changes be prevented in foods. Besides rendering the food unwholesome to the taste, powerful poisons, the ptomaines, are formed from proteins. Sickness and even death have been caused by these substances in ice cream, meat and other foods.

Salt and sugar have been commonly used as preservatives in the form of brine and syrup. These preservatives have little effect upon the composition of meats, fruits and vegetables other than the removal of a good deal of water. To what phenomenon which we studied in connection with plant roots is this due? Food-destroying organisms cannot develop in these strong solutions.

The canning industry, now grown to enormous proportions, is an invaluable method of preserving vegetables and fruits. It makes possible a wide distribution and usefulness of these important food stuffs. In our country, tomatoes, sweet corn and peas lead in importance of the industry in the order named. The convenience attending the use of canned goods is somewhat offset by losses of nutrients in the wash water. With peas, for example, while the water content increases from about 80 to 85 per cent during canning, the carbohydrates decrease from about 64 to 61 per cent of the dry peas. This loss is chiefly due to extraction of sucrose by the wash water.

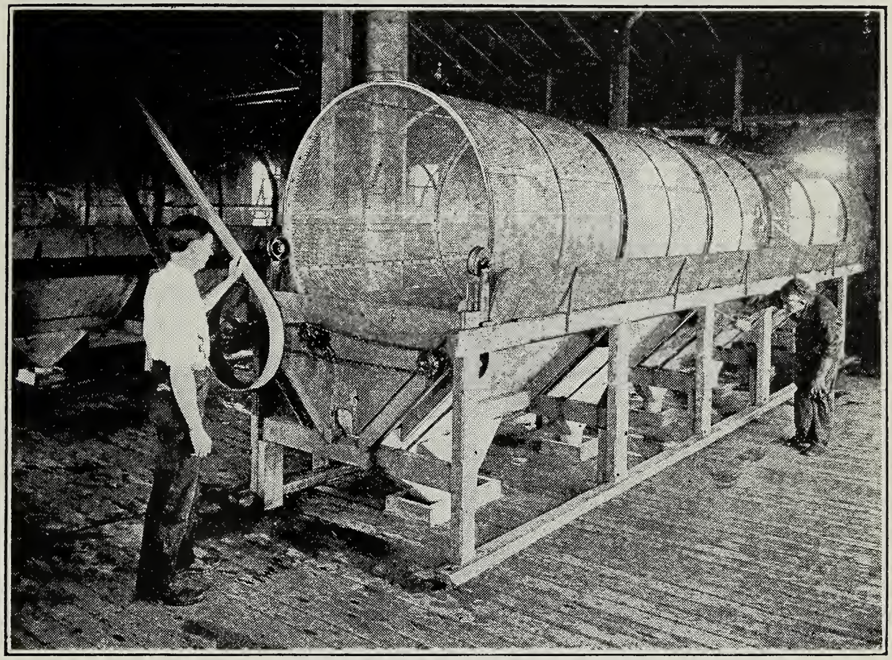


Figure 103. The "Squirrel Cage" of a canning factory. The peas are sorted by size in the revolving screen.

The pectin compounds have interesting and important relations to the making of fruit jellies. By boiling the immature fruits in water, pectose is changed to pectin. On cooling, this sets to a semi-solid mass and gives the "body" so much esteemed in jelly. An average is struck between food value and jellying quality by selecting the fruit at early ripeness.

The principle of the canning industry is the killing of bacteria and molds by heat and excluding them thereafter by tightly sealing the containing jars. The fact that high-grade products can be produced only from wholesome material and by cleanly methods gives the canning industry special merit.

Drying is a very old and very effective means of preservings meats, fruits, and other foods. By thus reducing the water content to a low percentage, the growth of organisms which cause decay is prevented. Vinegar acts as a preservative by virtue of its acidity, which few organisms can endure.

Chemical preservatives, as you know, have been the great "bone of contention" for several years between food manufacturers and executives of the food laws. Among these preservatives, sodium borate, or borax, and sodium sulphite have been added to meat and milk. Formaldehyde, or formalin, has been added to milk; and the sodium salts of two organic acids, benzoic and salicylic, have been added especially to fruit products. The use of the latter has been justified by some persons on the ground that they occur naturally in certain fruits. Some preservatives, when consumed by healthy persons in the small amounts one would possibly obtain in preserved foods, have been found not to be appreciably injurious. It is possible that some weak systems would be unfavorably affected by continued eating of such foods. The use of preservatives is undesirable, because it makes possible the canning and sale of stale and unfit material which would otherwise quickly disclose its condition by decay. The use of most of them is now prohibited by law. The preservation of "smoked" meats by creosote compounds of the smoke is virtually a chemical method. Copper salts have sometimes been used to color vegetables and improve their appearance. Their use is now prohibited by the national food laws. It is well to remember that copper, aluminium and especially lead compounds are poisonous when eaten in appreciable quantities. Hence, one should avoid cooking or storing strongly acid food stuffs in vessels of the metals.

Two types of food label. The dairy and food laws of a certain state provide a penalty for the making or selling of baking powders in packages not plainly labeled with the commonly known names of the ingredients contained therein. The essential parts of labels from the packages of two different manufacturers of baking powders are given. Observe how A warps the truth. The objections to alum are mentioned in the text.

A

No Alum No Ammonia
remains in food prepared with
............................Baking Powder.

This baking powder is composed of the following ingredients and none other: Soda, acid phosphates, corn starch, sodic aluminic, sulphate and white of egg.

B

This baking powder is composed of the following ingredients and none other: Bicarbonate of soda, calcium acid phosphate, corn starch, alum and white of eggs.

Pure Food Laws. The certainty of purchasing pure and wholesome foods at market is being made continually stronger by the creation and operation of food laws. Chemical analysis is the "court of last resort" as to whether or not foods are adulterated. In the case of many materials, as spices, beverages and cereal products, the microscope offers a means of rapid detection of impurity or fraud.

SUMMARY

The food requirements of man are more varied than those of the lower animals. Like the other animals, however, he needs a certain amount of protein for growth and repair. He needs, too, increasing amounts of carbohydrates and fat in proportion to his muscular activity. Meat, fish and eggs supply chiefly protein, while the cereal grains supply the necessary fuel values for muscular work. In proportion to their weight, children require much more of these food compounds than adults.

Vegetables and fruits are of value for their laxative and flavoring effects. They also supply basic elements, which neutralize the acid elements of meat and eggs. By the latter use they spare the valuable protein compounds.

Cooking does not change the composition of meats appreciably, though it adds to their flavor. Compounds extracted by water in boiling or stewing are kept in the meat by roasting or frying. The making of breads includes fermentation produced by yeast acting upon carbohydrates. The carbon dioxide produced in this way swells the dough, which owes its elasticity to the proteins of the gluten. By baking, some of the starch is converted to soluble or volatile compounds which produce flavor.

Canning makes possible a wide use of important food materials at a small loss of food value. It depends upon the killing of decay-producing organisms in wholesome materials and excluding their further entrance. Drying is a very effective means of preservation. The use of chemical preservatives is of questionable character. This is chiefly because it favors the use of unwholesome food materials.

The proper balancing of protein and fuel values requires careful consideration of efficiency and economy. One must also meet special requirements of the body by a variety of food selection. The pure food laws assist one to obtain pure and wholesome food stuffs.

QUESTIONS

1. What is dietetics?
2. Why does the feeding of man require special attention?
3. What is the largest factor producing fuel requirement in man when awake?
4. What two factors make the fuel requirement of children high?
5. What are the chief compounds supplying energy or fuel value in foods?
6. Is sufficient protein supplied by a quantity equal to that lost by wear from the body of an adult?
7. What are the average amounts of protein and of energy consumed by a man daily?
8. Name three food stuffs which supply chiefly protein? Three which supply energy?
9. What are two chief values of vegetables and fruit in diet?
10. What important chemical element is largely removed in making flour from wheat?
11. What is the composition of wheat gluten?
12. What compounds are formed or added in manufacturing breakfast foods?
13. What compounds produce flavor in fruits?
14. By what changes is cider produced? Vinegar?
15. What difference in effect upon the composition of meat is produced by boiling as compared with frying?
16. Does pasteurization affect the digestibility of milk?

17. How is the raising of bread dough caused by yeast? By baking powder?

18. What chemical changes occur in the baking of bread?

19. Why is soup-making preferable to stewing or boiling vegetables?

20. What method of cooking retains the most food value in the potato?

21. What is the cause of changes of composition in stored vegetables?

22. What change occurs in potatoes kept near freezing?

23. What compounds produce the flavor of spices?

24. What compound gives stimulant action to tea and coffee?

25. How is black tea prepared? Coffee?

26. What are the chief constituents of cocoa?

27. What is meant by the physiological balance of foods?

28. Name one important balance of this kind.

29. What is the objection to an excess of acid-forming elements in the ration?

30. Name one high acid-forming and one high base-forming food stuff.

31. What food stuffs would you select in planning a menu so as to be economical of cost?

32. How does refrigeration act in preserving foods?

33. How do salt and sugar act as preservatives?

34. Upon what chemical change is jelly-making dependent?

35. What are the beneficial effects of canning food stuffs? Of drying?

36. Why is the use of chemical food preservatives undesirable?

37. Why should one avoid cooking acid food stuffs in copper or aluminum vessels?

38. By what two scientific means are the pure food laws made effective?

CHAPTER XIV

MISCELLANEOUS MATERIALS OF IMPORTANCE IN DAILY LIFE

Suppose you were asked to name some material common to daily life but entirely free from any relations to the science of chemistry. Would that not be a quite hopeless task? One cannot avoid the realization that chemical composition is responsible for the valuable properties of many common things about us. Moreover, in the preparation or use of many of these things interesting and important chemical reactions occur. Let us select some of the materials most useful in daily life and dependent upon principles of chemistry for their preparation and properties. Some of these will be especially useful in the home, others about the farm. Among them are cloth fabrics, materials for the construction of dwellings and agents for warring upon insect and fungus enemies of plants. Knowledge of the composition and action of these materials will increase the interest and efficiency of the housewife and farmer in their work.

Next in importance to man after food are clothing and shelter. Clothing, as you know, is made from cloth fabrics manufactured from certain plant and animal fibers. The most useful of the plant fibers are cotton, flax and hemp. Wool and silk are the chief fibers obtained from animals.

Cotton is used in greater quantities than the other plant fibers. It is the hairy fiber attached to the seeds of several varieties of plants belonging to a single large family. Our country leads the world in the production of cotton. The variety grown in the southern states is a low shrub whose pods or "bolls" mature in December to January. It yields about 300 pounds of impure cotton or "lint" per acre. Over three million tons of the fiber are produced yearly in the

United States. By the use of the ginning machine the seeds are removed from the fiber. The former yield the cottonseed oil of commerce.

Cotton fiber is the purest form of cellulose found in nature. Each fiber is about an inch long and one thousandth of an inch in diameter. It is flattened or collapsed, and spirally twisted, as shown in Figure 104. Its fibers are thus well suited for spinning into threads, on account of the natural interlocking of the fibers. Very short cotton is twisted into yarn. A certain water content of cotton fiber is necessary for good spinning quality. Too much makes it sticky, while too little makes it brittle and weak. As it contains only 5 per cent or less in the bale, it is usually necessary to moisten the fiber in the spinning rooms. Lancashire, England, has a climate very favorable to good working quality of cotton.

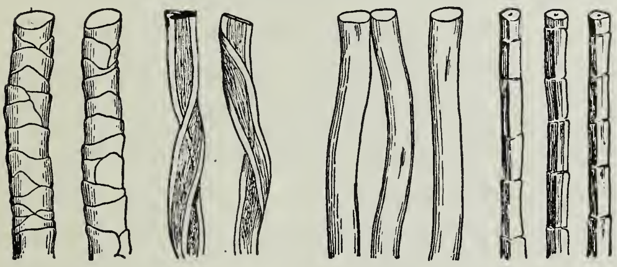


Figure 104. Drawings from microphotographs of cloth fibers. From left to right: wool, cotton, silk, flax.

The thread is whitened by boiling with steam, treating with bleaching powder and washing with soap. It is then "sized" by soaking it in starch paste. This increases its weight and strength. If it tends to be brittle, it is dipped in either tallow or paraffin. Cotton fabric is woven by machinery by crossing weft or "woof" threads alternately over and under long parallel threads called the warp. The raw cloth is bleached by bleaching powder and alkalies. This treatment dissolves grease and converts incrusting compounds to soluble forms. It is then weighted by starch paste, with or without clay. This process is called "calendering."

Mercerized cotton is made by treating cotton first with strong alkali and then with sulphuric acid. The process is named from John Mercer, who discovered the contracting and clearing effect of alkali upon cotton fibers. The alkali removes the outer surface of the fiber and swells it to round, cylindrical form. Can you not suggest what corrective effect the acid treatment has in following the alkali? The product is stretched while still gelatinous from the treatment. Mercerized cotton is heavier and stronger than the untreated fiber and has a silky luster. The luster is produced by reflection of light from the rounded fibers.

Artificial silk is made from collodion, which is a solution of nitro-cellulose or gun cotton in ether. This is the solution called "new skin," used for covering cuts and bruises. Nitro-cellulose is made by treating cotton with a mixture of strong nitric and sulphuric acids. It is, as you know, the basis of powerful explosives, and very inflammable. Collodion is squirted into dilute nitric acid in fine streams which harden to threads. The product is then treated with reducing agents, which greatly decreases its inflammability. This artificial silk is weaker and less elastic than silk. It chews to a pulp, while the latter falls apart.

Flax, or linen, is the most important spinning fiber, next to cotton. It is obtained from a shrub which thrives in cooler climates than cotton. Russia produces over one half the world's supply, but Belgium and Ireland grow the best quality. The crop is harvested and dried just as it begins to turn brown. The fibers are then separated from the wood of the stem by the process called "retting," which is a bacterial fermentation produced by soaking in water. Certain enzymes of the bacteria destroy the pectin compounds which incrust the fibrous cells of the stem and bind them together. The retted stalks are crushed and the fibers combed out. These form about thirty five per cent of the stem. They are bleached in the same manner as cotton. Each fiber is a plant cell having the form of a long, cylindrical, untwisted, thick-walled tube, with closed ends. While less elastic than cotton, it takes a fine polish when starched and ironed, on account of its very smooth surface. Hence the high favor of fine linens.

Hemp yields a coarse fiber unsuitable for cloth fabrics. The resistance of this fiber to decay in water and its great strength make it valuable for twine, rope and sacking. The plant is a slender shrub, eight feet or more in height, adapted to mild climates. The central states of this country, including Kentucky, Illinois and Missouri, form a hemp-growing region. Hemp fiber is an unbleachable, ligno-cellulose. The strongest ropes are made from manila hemp, obtained from the petiole of a species of banana in the Philippine Islands.

Wool is a fine, soft grade of hair. Some goats, as the cashmere, produce long, soft hair prized for cloth-making. As you see by Figure 104, wool has a rough, scaly covering. Its strength is due to the cortex, the portion between the covering and the pith. A special machine is used for testing the breaking strength of the wool fibers. Our leading sheep-raising states, Wyoming and Montana, support about four and a half million head of sheep each. Billings, Montana, is said to be the greatest wool-shipping center of the world. The average weight of a fleece is eight pounds, but on the ranges of alkali soils the weight is much less. The latter wools are also of poor quality, due to the destructive action of the soil dust on the fiber. The total wool clip of this country in 1909 was estimated as worth the enormous sum of seventy-eight million dollars.

Raw wool is very greasy and dirty on account of the natural oily secretion or yolk of the sheep's skin and the residues from perspiration. The whole material, called suint, is removed by washing the wool in alkali. The burrs and other dirt are removed by charring with acid, drying and shaking. Long-staple wools have fibers one and a half or more inches long. Like other hair, wool is a protein compound. It differs from albumin of the blood chiefly by containing a little less carbon but more sulphur. It has a remarkable affinity for water, which makes it liable to adulteration. As much as fifty per cent may be present without producing a moist feeling.

Silk is the secretion from which the silk worm makes its cocoon. In China and India the wild worms feed on oak leaves. The domesticated worms are fed on mulberry leaves. At hatching they are no larger than pin heads. In the oriental countries the eggs are sometimes carried on the human body for hatching. The worms grow rapidly to a length of about three inches, when they spin the cocoon. Before they can pupate and emerge as moths they are killed by heat. The gum by which the fiber is cemented is softened by warm water and the thread is unwound. It is a more slender fiber than cotton, but its length, from a single cocoon, may reach two thousand yards. Several fibers are wound together to form a thread. In 1907 Europe used twenty-five million and our country used fifteen million pounds of raw silk. China furnishes one half the world's supply, and Japan and Italy each furnish about one fourth. Like wool, silk is a protein compound. Satin is made by weaving cotton weft on silk warp.

Figure 105. Feeding silk worms in Japan.
From King's "Farmers of Forty Centuries" by permission.

The extensive dyeing industry has risen from the demand for beautifying cloth and textiles. In ancient times dyestuffs were obtained chiefly from plants. There was the red of madder, the yellow of crocus and the blue of indigo. The famous purple of Tyre was prepared from a secretion obtained from shellfish still found in the Mediterranean Sea. Only a few drops of the prized secretion were obtained from each fish. The American colonists dyed with metals. Iron buff, for example, was obtained by impregnating the fabric first with ferric acetate solution and then with the leachings of wood ashes. What familiar iron compound would be formed in the fiber by this treatment? Manganese brown was similarly made from potassium permanganate. The fabrics were, of course, finally washed free from soluble salts. Most of these dyes were far from satisfactory. Either they were too loosely held or "fixed," by the fabrics or they lacked endurance, or "fastness," to light and washing.

Coal tar dyes, however, possess fastness to a high degree. The discovery and development of these compounds has furnished material for one of the most fascinating chapters in the history of chemistry. In 1856 a young English chemist was attempting to make the alkaloid quinine from aniline. The latter is a nitrogen-containing derivative of benzene, which is a hydrocarbon forming the basis of the coal tar compounds. Instead of quinine a beautiful violet dye was obtained. A few years later the discovery of alizarine among the products obtained from benzene opened up the wonderfully fertile field of work of synthesizing the aniline or coal tar dyes. Over fourteen thousand of these compounds have been produced from the tar which once appeared to be a useless waste product in the production of illuminating gas from coal. The young chemist who began this work, or the late Sir William Perkin, has been highly and fittingly honored the world over.

The aniline dyes are divided into those of acid and those of basic character. This, at once, suggests that their fixation may be of chemical nature, as indeed it is. Basic dyes fix directly on wool and silk, that is, the fabrics dye by mere immersion in the dyeing fluid. This is because the animal fibers are slightly acid in nature. Acid dyes, however, fix on these fibers only from baths to which acid has been added. They require precipitation on or in the fiber, as it were, by stronger acids. Methyl violet and Bismarck brown are basic dyes.

The vegetable fibers are, for the most part, quite neutral to dyes. When a dye is taken up directly by plant or animal fibers it is called a "direct" dye. Congo red was the first discovered of the direct dyes. It was observed that solutions of the dye filtered through paper leave the paper dyed. The plant fibers generally require mordanting to fix dyes. Clay and aluminium oxide are common mordants. In some way these substances when suspended in the fabric increase the affinity between the fibers and the dye. A dye requiring the use of mordants is called "substantive." Basic dyes fix on plant fibers when tannic acid or oil are used as mordants. They are not so fast as the acid dyes.

Dyeing requires previous careful cleaning of the fabrics. Silk is prepared by removing its natural gum with soap. Its fixing power is increased by soaking in ferric nitrate solution or weak acetic acid. Then it is immersed in a solution of the dye with dilute sulphuric acid. Sometimes it is also immersed in solution of tin chloride until its weight increases several fold. Finally it is made lustrous and elastic by oiling. Cotton and linen can be cleaned by soap and dilute alkali. Direct dyes fix best on these fibers when such salts as sodium chloride or sulphate are present.

Fastness of dyes to light is tested by stretching the dyed fabric across a small opening in the shutter of a south window. If the color of the exposed area fades in one week or less the dye is regarded not fast. If four weeks or longer is required to produce fading, the color is regarded as fast. Fastness to soap is tested by heating the dyed fabric to

140°F. in a strong bath of laundry soap. Skeins of cotton and of silk, thoroughly cleaned from grease and dirt, are immersed with the fiber. If only the soap solution is colored, the dye is regarded as fast. If either skein is colored, the dye is not fast.

Cleaning of fabrics, especially the removal of various stains, is an ever practical problem of the housewife. It also involves the use of chemical properties and reactions. Commercial cleansing is roughly divided into dry cleaning and spot cleaning. The former is also called chemical or French cleaning. It is a chemical process in the sense that solvents for fats and mineral oils are used to remove grease. It is dry in the sense that these solvents are liquids other than water. Benzine, benzol and chloroform are the solvents generally used. The first is a mixture of hydrocarbons related to kerosene and paraffine. The second is the foundational hydrocarbon of coal tar oil. The last is a derivative of the simplest hydrocarbon related to paraffine. Carbon bisulphide and other solvents which might be used are either too expensive or have disagreeable odors. Benzine is both volatile and very inflammable. Would you regard it desirable for use in open tubs? On the commercial scale the clothing is treated in closed tumbling machines which remove the dirt by agitation, while preventing loss of the solvent by evaporation. Some pure soap is added to the cleaning fluid. Some of these machines are so made that the chamber can be filled with carbon dioxide. How would this decrease the fire risk? The dry cleaning method is necessary for the cleaning of white leather goods, which are tanned with alum, because water is injurious to such goods by its solvent action.

Spot cleaning includes the removal of stains due to pitch, paint, fruit juice, ink and such substances. Wood alcohol, with soap and a very little ammonia, is effective in removing paint, pitch and tar. One should always test the fastness of the dye to such cleansers by treating a bit of the fabric before proceeding with the work. Violet and green dyes are injured by wood alcohol. Since paints are bound or "set" by linseed oil, they can be removed by the same solvents used for grease. Benzine and benzol are good cleansers for paint, pitch and tar. Turpentine is especially useful for paint and pitch. Aniline is the best solvent for varnish and resin. Common ink is iron tannate. It is dissolved by certain organic acids such as acetic and oxalic acids. Salts of these acids are also helpful. How would you explain the action of the home agents, lemon juice, vinegar and cream of tartar, for removing ink stains? Indelible inks are made from aniline dyes, for which aniline is the universal solvent. Iron rust or mold can be dissolved completely only by dilute mineral acids, though the organic acids are useful. After using any of these stain removers it is well to soak the fabric in weak mineral acid. Finally, of course, the fabrics must be thoroughly washed. Grass stains, due to chlorophyll, should be removed by common alcohol. Blood is not soluble in the fat solvents. Like other soluble protein materials, it dissolves better in cold than in hot water. This is because heat coagulates soluble proteins. On the other hand, the colored compounds of fruit stains are more soluble in hot than in cold water.

Bleaching is frequently necessary to complete the removal of stains, especially of grass, blood and fruit stains. This is practically an oxidation of colored to colorless compounds. For this purpose immersion in solution of bleaching powder or, better, of the related sodium hypo-chlorite, is beneficial. Potassium permanganate is safer than the chlorites for use on wool or silk. It is necessary to follow with an acid solvent to remove the manganese. The bluing of white fabrics in washing is merely a process of weakening other colors, such as yellow, by blue. The common bluing compounds are indigo and aniline dyes. Old fashioned bluing was an iron compound, which sometimes left rust spots on the cloth. Sodium peroxide is also used as a bleaching agent. Perhaps the safest efficient bleach is produced by chlorine released electrolytically from salt solution in which the fabric is suspended. What have you previously learned to be the active agent in bleaching by chlorine?

Paints and varnishes, in relation to their composition and durability, are materials of vital concern to the farm and home. It is desirable to secure the longest life and most efficient protection against the weather from exterior coatings of paint. The housewife should know also what methods of cleaning can be applied safely to interior finishes. For many years lead white has been the standard body material for paints applied to exterior woodwork. This is basic lead carbonate, which contains more lead than the common carbonate. Paint bodies of this sort are spread by mixing with linseed oil and "cutting" or thinning with turpentine. The thinned oil deposits the pigment in the surface tissue of the wood. The thinner then evaporates and the oil dries and "sets" the paint, forming a protecting, skin-like coat. By referring to the chapter on the plant and its products you will recall what chemical change causes the hardening of the oil. Boiled oil sets more rapidly than raw oil and hence is less penetrating. It is thus unsuited for the first or "priming" coats. Lead is not fit for use inside chemical laboratories, where hydrogen sulphide is present in the air. In such places zinc oxide is used to replace the lead. What compounds of lead and zinc are formed by the action of the hydrogen sulphide gas on these paints? The compound formed from lead is black while that from zinc is white, so that zinc white is least injured by hydrogen sulphide. Other colors than white are obtained by mixing carbon black and various colored pigments with the lead or zinc. Thus lead chromate gives yellow, chromic oxide gives green, ferrous ferrocyanide gives blue, and so on. The best vehicle for lead is a thinner composed of 95 parts linseed oil and 5 parts turpentine. Japans or "driers" are often mixed with paints to hasten their drying. These are compounds of lead or manganese with oil or resin. They assist in the oxidations which produce the drying.

Paints are of great service in protecting bridges and other steel structures, as well as steel and iron tools, from destruction by rusting. For such surfaces ferric oxide is mixed in oil with other inert materials, such as calcium carbonate and clay. Venetian red and Prince's metallic are made in this way. Small articles are dipped, while large surfaces are sometimes sprayed with the paint. The brown color of umber and of sienna are due to the addition of a small amount of manganese oxide to the iron oxide. Salts of casein with sodium and other bases are the pigments of casein paints.

Ready mixed paints are products of a great industry, built on the extensive need for paints. It was estimated that in 1907 seventy million gallons of such paints were used in the United States. Unprincipled manufacturers have sometimes attempted to profit from adulteration of these materials. Such cheap materials as chalk, gypsum and clay have been substituted for lead. In lawful trade zinc oxide is mixed with white lead to make leaded zincs and

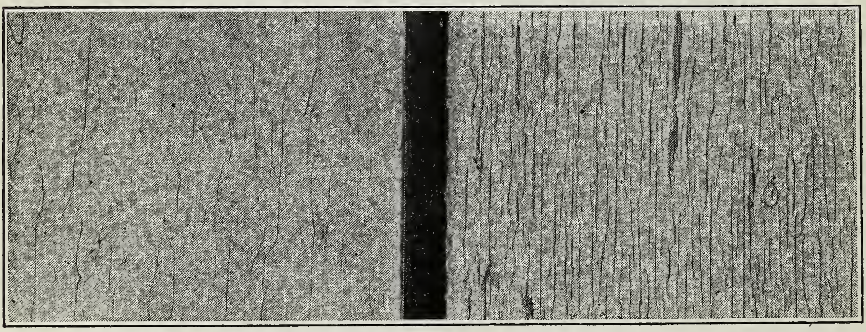


Figure 106. The durability of house paints exposed to the weather. The paint on the right contained too much zinc and too little lead.

zinc-lead whites. This mixture can be carried to an undesirable excess, for the zinc paint pulls and spreads poorly in cool weather. Practical painters agree that not over one third of such a white should be zinc oxide. Further adulteration has been practiced by using the cheaper benzine in place of turpentine and rosin in the place of drier. Paints made from such materials fail to penetrate and soon crack or peel. The Experiment Station of North Dakota has taken the lead in the attempt to regulate the sale of ready mixed paints by state laws. By these laws the manufacturer is required to supply to the public products of guaranteed composition.

Varnish of the highest grade is made from fossil products of tree resins. Gum copal of Zanzibar is such a material. These resins are boiled with linseed oil and thinned with turpentine. Rosin, a mixture of fresh resins, is an inferior substitute. Shellac is prepared by melting these gums and allowing the liquid to cool and harden in thin sheets. It is pared into scales and dissolved in alcohol.

Would you think the use of benzine or turpentine advisable for cleaning paint and varnish? Is it not readily seen that the oil and resin solvents used to apply these materials will also either deface or remove them? The safest cleanser for interior painted or varnished surfaces is a high-grade, practically neutral soap, such as Ivory soap, applied with water and a soft chamois skin. If crude, alkaline soaps or ammonia be used there is danger of dissolving the surface of varnish and deadening its luster.

Pure soap solution cleanses in two ways. It emulsifies the fat or grease, that is, it takes it into supension as microscopic droplets, as it exists in milk. It also dissolves the fat or grease by its weak alkalinity.

Cements and mortars are widely used in daily life. By a few minutes thought you can state many ways in which they are of service. Cement is mostly basic calcium silicate.

Natural cement rocks were discovered about 1800 at Louisville, Kentucky, and in other parts of our country. These rocks contain such proportions of calcium, aluminium and silicon as when heated produce a material which sets when wet. Portland cement was patented in 1827 by a brick maker living near Portland, England. It has practically put the natural cements out of use, because it is more uniform in composition and more dependable. The product is made by heating lime and clay in a special furnace. With both Portland and natural cements the material is heated until fusion begins. The chemical reactions are left incompleted; but they are the more complete the finer the state of the materials used. They are also made more complete by thoroughly mixing the materials with a little water, and by heating to as high a temperature as possible. The fused product, called clinker, consists of crystal masses cemented together by an uncrystalline material. The crystalline mass is not a pure compound; but it always contains silica and lime in proportions of about 25 per cent and 67 per cent respectively. It also contains about 35 per cent of ferric and aluminium oxides. The cementing part contains more aluminium, less calcium and much less silicon than the crystalline part. In manufacturing cement the kilns are gradually heated to about 1400° C. The material first dries. Then, at just above 800° C., the organic matter and carbon dioxide are lost. Finally, as fusion begins, the lime combines with silica and with alumina to form salts new to the mixture. The chief aluminium compound formed is tricalcium aluminate. This contains one molecule of alumina or aluminium oxide, acting as an acid, combined with three molecules of lime, or calcium oxide. The first setting of cement is due to this compound, which combines with eight to twelve per cent of water. Later in the setting process the calcium silicates are decomposed by water and some calcium hydroxide is set free. The silicic acid also, when set free, forms a jelly-like coat around the particles of cement. No water can penetrate this coat, and the free water in each such particle for reactions inside it causes the hardening and setting of the mass even under water.

Concrete is used in place of cement for rough work on a large scale, such as piers and walls. Historic Roman buildings were constructed from concrete, the use of which dates from ancient times. It consists of rock or cement fragments bound together by cement. The binding effect is the more complete the more complete the contact of the fragments and cement. How would you explain the superiority of rough over smooth fragments? Compactness is an important quality in finished concrete. Porous material is subject to accumulation of water and the splitting action of freezing. For this reason very coarse rock fragments are to be avoided. Some of the salts in sea water tend to react very slowly with the compounds of cement;

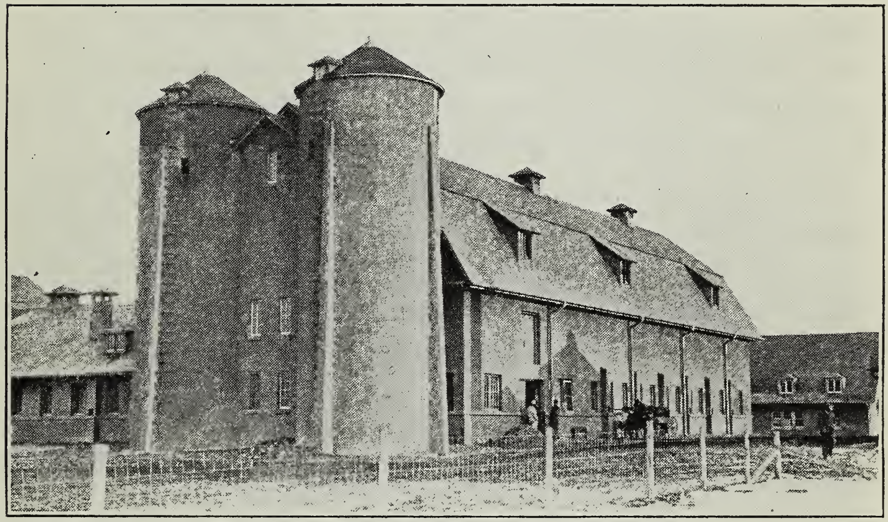


Figure 107. Splendid barns and silos built with concrete. They are long lived and almost wholly fireproof.—(Courtesy Universal Portland Cement Co.)

and carbonated water dissolves calcium from it gradually. These agents do little harm, however. Where sewage is exposed to the air in contact with concrete it sometimes rapidly destroys the latter. This is due to the formation of sulphuric acid by oxidation of hydrogen sulphide and the solvent action of the acid on the binding compounds of the cement. Silage does not dissolve cement to any extent, as is sometimes thought. With all these materials, however, there may be spreading force exerted by the formation of salt crystals in the cavities of the cement. Both physical and chemical destruction are, therefore, reduced by making a uniform, compact product.

Mortar has been used from very ancient times. The Romans made excellent mortar, often using sand and clay in preparing it. Plain mortar is calcium hydroxide, made by slaking quicklime or calcium oxide with water. Sometimes hair and sand are mixed with it. Sand imparts strength, serving about like the rock in concrete. Hair gives a body to the mass which makes it spread better and helps hold it together while drying. The chief process causing setting of mortar is drying. While the mass is still moist the calcium hydroxide may react with carbon dioxide of the air. What compound would be produced in this way? The process forms a protective coat at the surface of the mortar and the carbon dioxide does not penetrate far. Even in Roman mortars twenty centuries old only the surface layer was found to contain calcium carbonate.

Plaster is prepared from gypsum, calcium sulphate combined with two molecules of water. That used in building the great pyramids of Egypt was made from impure gypsum. In 1765 the great French chemist Lavoisier discovered the chemical changes of plaster making. He found that by heating to 130° C. three molecules of water are lost from two molecules of gypsum. The product unites with water and sets, when the two are mixed. It is commonly known as

Plaster of Paris, a material much used for molds, casts and decorative work. If the gypsum is heated above 194° C., it loses all its water and "dead burns." In this condition it is so insoluble that it no longer sets when mixed with water. Plaster should be mixed sparingly with water. By this treatment the hydrated salt crystalizes from a saturated solution, and forms interlocking, radiate bundles of crystals. How would you expect this interlocking condition to affect the strength of the product? If the gypsum is slowly and indirectly heated to about 500° C. by the gases from the fuels, it does not "dead burn." Its water is driven off, but the product is soluble enough to set slowly when mixed with water. It produces the hard plaster of floorings. When mixed with mortar, this kind of plaster retards its setting and hardens it. Gelatin and starch paste, which have affinity for water, are sometimes mixed with plaster to delay setting and prolong the time during which it can be applied. Can you see how they act?

Insecticides are man's weapons in warfare against destructive insect parasites of plants. These parasites so sap and weaken the host plants as to decrease or ruin crops. Among them are included the potato bug, cabbage worm and many other destructive pests. To combat these different kinds of insects different methods must be used. Those which eat the foliage can be killed by poisoning the surface of the plants. If they are sucking insects, such as plant lice and some beetles they must be treated through their breathing pores or tracheae. These open along the sides of the abdomen. They may be closed by some substance which will spread over the surface of the body. Such insects may also be killed by some gaseous poison which can enter the tracheae. Still another kind of insect, which is protected by a scale, can be killed only by a gaseous poison, or better, by some caustic substance which will loosen the scale from the tree.

The standard remedies for all those insects whose worms or larvae eat foliage are compounds of arsenic. White arsenic or arsenious oxide is the most common compound of arsenic. It contains two atoms of the element arsenic combined with three atoms of oxygen. Dissolved in water it is a weak acid and combines with alkalies and metals to form salts called arsenites. It combines with two more atoms of oxygen to form arsenic oxide, which forms salts called arsenates. Sodium forms soluble salts with the oxides of arsenic, while calcium and some of the common metals such as lead form insoluble compounds. Which of these kinds of salts would you expect to give the greater service? It has been found that only very insoluble compounds of arsenic can be used without danger of killing the plants.

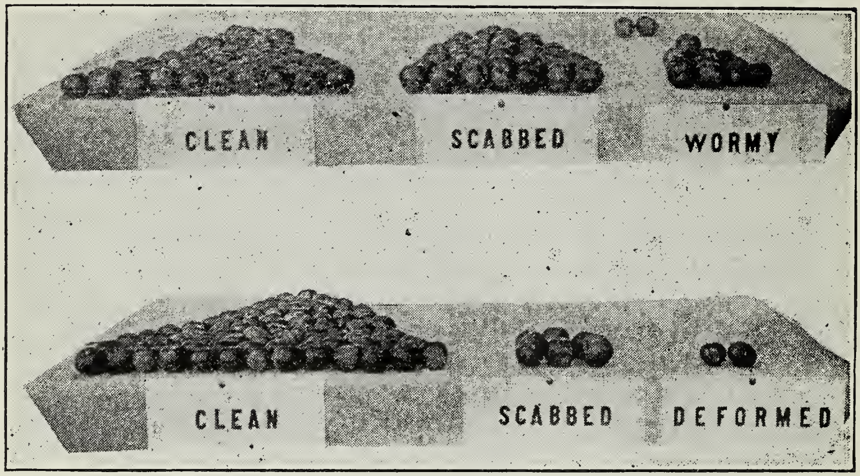


Figure 108. The good results from using insecticides and fungicides. The lower apples came from a tree sprayed with a mixture of lime-sulphur wash and lead arsenate. The tree yielding the upper apples was unsprayed.

Paris green was first used in our western states about 1860. It was applied against the potato bug, for which it is still the leading remedy. For several years it gave uncertain results, sometimes killing the plants. The trouble has been found to be due to soluble arsenic compounds. It can be prevented by adding an excess of lime water to the green before applying it. Paris green is made by boiling a solution of copper acetate with a solution of sodium arsenite. It is an insoluble salt of copper with both arsenious and acetic acids. By suspending it in water it can be sprayed upon foliage. When improperly made some soluble arsenic compounds may be present. These are liable to penetrate and kill the leaves. When an excess of lime is added, it reacts with them to form calcium arsenite, and prevents the injury. Pure Paris green contains almost 60 per cent of arsenious oxide. On account of the danger from soluble arsenic some states have limited by law the amount of soluble arsenious oxide permissible in this insecticide. Wisconsin allows the presence of 3.5 per cent.

Calcium arsenite is, as you may glean from the preceding paragraph, a safe insecticide. From what has preceded you can readily see how it is made. It is an insoluble compound which does not injure the leaf, but when consumed by insects it is made soluble and poisonous by their digestive fluids. This is the chief constituent of London purple, a waste product of the dye industry, formerly much used as an insecticide. Zinc arsenite is also an insecticide.

Lead arsenate is prepared by adding lead acetate to sodium arsenate. It is sold in the form of a paste ready to be suspended in water for spraying. Dry lead arsenate is of little use as it does not remain suspended well. This causes uneven application to the foliage and clogging of the spray nozzles. Lead hydrogen arsenate, or acid lead arsenate, is formed when some lead salts are added to sodium arsenate. This contains more arsenic than the natural salt.

Lime-sulphur wash is useful against insects with protective covering such as the San Jose scale of fruit trees. It is prepared by boiling sulphur with lime in the proportion of 1 pound of each to 2.5 gallons of water. For convenience, large amounts of the wash are prepared in elevated casks by passing live steam through the water. The wash is then diluted to the desired strength and siphoned off for spraying. As the wash is boiled it passes through deeper shades of yellow to an orange color. At the same time the calcium combines with the sulphur in several proportions. The compounds produced are called polysulphides. Calcium pentasulphide, the last of these, contains one atom of calcium and five atoms of sulphur. Only the use of the most finely divided form of sulphur, the "flowers," insures that the desired chemical reactions will occur. Impure lime containing magnesium produces reactions in which hydrogen sulphide is set free, and must be avoided. Sulphur wash acts first as a solvent upon the scale insects, loosening them from the tree. The scales consist of chitin, a hard protein substance related to hair and horn. These compounds are acted upon and made soluble by alkalies,

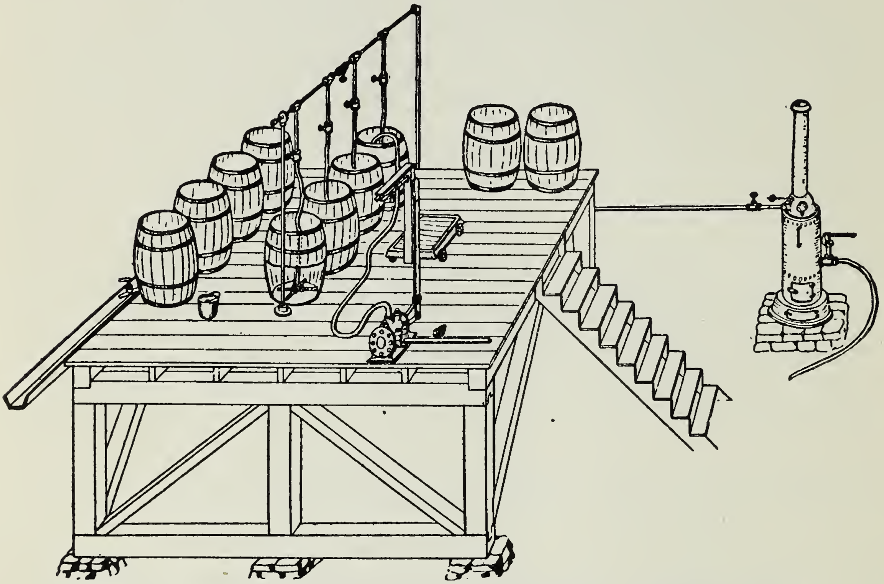


Figure 109. An economical outfit for preparing lime-sulphur wash. It includes a pump, for drawing water to the platform, scales for weighing the lime and sulphur and a steam boiler for heating the wash.

and the sulphides of the wash are alkaline. Then the sulphides which penetrate to the insect are oxidized by the air to calcium sulphate and free sulphur. These chemical changes and their products kill the insect.

Petroleum oils related to kerosene and paraffine are useful for destroying most sucking insects. These insects cannot be poisoned, since they feed only on the sap of the plant. The oils form a film over their bodies and suffocate them. Oils cannot be applied undiluted, nor can they be diluted, as you know, with water. Strong soap solutions, however, form emulsions with them. You will recall the nature of an emulsion from your study of milk fat. These preparations are called miscible oils. To prepare them, fish oil is boiled with strongest potassium hydroxide solution, in the proportion of one gallon to one and a half gallons respectively. Carbolic acid, kerosene and water are added in small amounts. This makes the soap solution. Why will not a sodium soap serve for this purpose? While the soap solution is still hot the paraffine oil is stirred in. This should be added in the proportion of about ten gallons of oil to one gallon of soap solution. This makes the miscible oil, which can be diluted as desired, with from twelve to fifteen times its volume of water, for the final spray fluid.

Hydrocyanic acid, commonly called Prussic acid, is a powerful gaseous poison. It is formed by adding potassium cyanide to an excess of strong sulphuric acid. It is especially useful for killing insects in crowded greenhouses. It is also useful against vermin in dwellings. Scale insects on small fruit stock may be treated in closed buildings. Larger trees are inclosed in tents for treatment. In all these cases the space to be treated is measured and one ounce of pure potassium cyanide is used per 100 cubic feet. To avoid danger the building should be opened and ventilated before entering after fumigation.

Carbon bisulphide is very useful against grain weevils. It is a colorless, volatile liquid containing one atom of carbon to two atoms of sulphur. When placed in open dishes at the surface of the grain its heavy vapors sink, and should be allowed to escape at the bottom of the bin.

Fungicides are materials used to kill parasites upon plants. To kill them without injuring the host is a delicate task. Many plant diseases, such as the rusts and blights, are due to plants of microscopic size belonging to the same great group as the mushrooms. These parasites enter the soft tissue of the host, frequently through the stomata of the leaves, and deprive it of food. They thus weaken or even kill the host crops. It is difficult to apply poison to them without danger that it will enter and injure the host.

Sulphur and some of its compounds were used as fungicides as early as 1880. They have been used a great deal to suppress mildew in greenhouses. Potassium sulphide is esteemed for the purpose, sprayed in a solution of 6 per cent strength. The base is so strong and the acid so weak in this salt that stronger solutions are so alkaline as to kill the plants. A modern preparation of sulphur set free from its compounds by chemical reaction is very effective. It is an extremely finely divided material known as "atomic sulphur," which is suspended in water for spraying.

Copper, in the form of some of its compounds, has been the standard fungicidal agent for a long time. Copper sulphate solution is too acid for use. Copper ammonium carbonate solution, made by dissolving copper carbonate in a slight excess of ammonia, is sometimes used as a fungicide. Bordeaux mixture has been the leading fungicide since about 1880. It is a suspension in water of insoluble mixed compounds of copper and calcium with sulphuric acid. These compounds are formed as a precipitate when copper sulphate solution is added to limewater. In order to insure that it will remain suspended well when mixed with water it must be precipitated in the finest particles possible. This result is accomplished by dissolving the lime and copper sulphate each in one half the volume of water to be used. After the limewater is cold the two solutions are poured at the same time into a mixing barrel. They must be poured slowly with constant stirring. The proportions used are 3.5 pounds of pure lime to 10 pounds of copper sulphate in 50 gallons of water. Unless an excess of lime is present, the mixture is liable to contain enough soluble copper to injure the foliage. This is liable to be the case, if only impure lime can be had. To avoid this trouble, a little of the mixture is filtered and tested by adding a few drops each of acetic acid and potassium ferrocyanide solution. If soluble copper is present the liquid turns brown as a result of the presence of copper ferrocyanide. More lime water is added until the mixture no longer gives this test. When Bordeaux mixture is applied to foliage, the copper gradually becomes soluble, chiefly by the action of carbonic acid. This reagent is formed from carbon dioxide which, as you will recall, is a product of the respiration of the leaf. These changes are usually sufficient to kill the parasitic fungi without injuring the host plants. Bordeaux mixture derives its name from the province of France where the favorable effects of lime and copper salts together upon grapes was first observed.

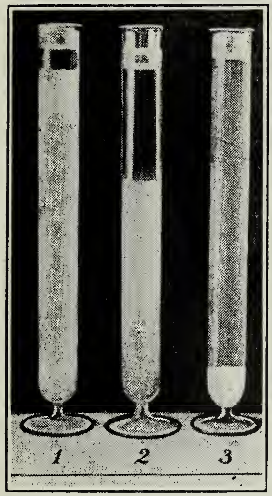


Figure 110. Bordeaux mixture properly and improperly made. 1 and 2 were photographed 3½ hours after preparation. 3 was photographed 15 minutes after preparation. In 1 the lime solution was first cooled and then poured simultaneously with the copper sulphate solution into a mixing vessel. In 2 the solutions were mixed while the limewater was hot. In 3 one solution was poured into the other while the limewater was hot. It is desirable to have the Bordeaux mixture remain suspended as long as possible.

Disinfectants are frequently necessary materials in the home or stable. They may be used either to rid rooms of bacteria causing infectious diseases or to render decaying and fecal matter less objectionable.

Carbolic acid and related coal tar compounds are commonly used for this purpose. At ordinary temperatures carbolic acid is crystalline, but it becomes liquid by heating gently. The liquid can be mixed with solid matter. For spraying surfaces it is dissolved in water to a solution of about five per cent strength.

Formaldehyde is a powerful disinfectant. It is a gas produced by oxidation from methyl alcohol or "wood alcohol." One can obtain it from the pharmacist as formalin, a 40 per cent solution of formaldehyde in water. This can be diluted to any desired strength for spraying. In disinfecting rooms the formaldehyde is forced in from the outside. The rooms are then aired.

Mercury bichloride, or corrosive sublimate, is a powerful disinfectant and poison. It is a salt formed by the union of one atom of mercury with two atoms of chlorine. A 0.1 to 0.2 per cent solution of this salt is very commonly used as a disinfectant wash applied to the human body. Much stronger solutions are used as sprays and mixed with material to be disinfected.

These three disinfectants are all extremely poisonous to animals, as well as to bacteria, and must be used only with great care and judgment. Accidental deaths of human beings from taking carbolic acid or corrosive sublimate internally are too common.

Calcium hypochlorite, or "bleaching powder," is a rather mild and favorite disinfectant. It contains one atom each of calcium and oxygen combined with two atoms of chlorine. Frequently it is wrongly called "chloride of lime." It is a white powder which gives off chlorine gradually. This chlorine decomposes water, forming hydrochloric acid and releasing oxygen. The latter acts as a disinfectant by oxidizing the organic matter of bacteria. In the same manner it acts as a bleaching agent by oxidizing colored to colorless compounds. Would you expect bleaching powder to disinfect perfectly dry material?

Hydrogen peroxide, consisting of two parts each of hydrogen and oxygen, also acts as a bleaching and disinfecting agent by releasing oxygen. As commonly sold it is a four per cent solution in water, with some preserving agent added.

SUMMARY

Among the multitude of materials useful in daily life there is none free from dependence upon chemical properties or reactions for its value. Clothing fabrics are made from plant and animal fibers, which are carbohydrate and protein compounds respectively. Differences in chemical properties cause the animal fibers to take up dyes more readily than the plant fibers. The latter generally require the use of some mordant deposited in the fiber, which increases their affinity for the dye. Cleansers and stain removers act generally as solvents for compounds soiling clothing fabrics, while bleaching agents act by oxidation. Care is necessary that these materials may not remove the dye from the fabric.

Paints of highest grade are pigments of metallic compounds mixed with linseed oil and thinned with turpentine. The turpentine acts as a solvent, carrying the pigment into wood, and the oil dries and "sets" the paint by oxidizing. Varnishes are plant gums and resins dissolved in linseed oil. Any fat solvent must be avoided in cleaning painted or varnished surfaces.

Mortar, plaster and cement are compounds of calcium. The first is made from quicklime and the second from partly dehydrated gypsum. Both compounds combine with water when made up, and the free water left dries out. Cement is made by heating a mixture of lime and clay very hot. Its chief compounds are salts containing calcium combined with silicon and with aluminium as acid-forming elements. Calcium aluminate "sets" by combining with water, while the silicates are decomposed and so protect the cement particles that setting proceeds even under water.

Insecticides and fungicides are mostly practically insoluble compounds which are suspended in water and sprayed upon crops to kill parasites without injuring the host plants. Arsenic compounds are applied to insects and copper compounds to plant parasites. Insects not reached by poisons at the surface of the foilage are either suffocated by paraffine oils, sprayed as emulsions in soap solution, or loosened from the plant and poisoned by sulphides of calcium. The insoluble poisonous compounds are made gradually soluble by solvents within the insect and on the surface of the foliage. Disinfectants kill bacteria by acting either as poisons or as oxidizing agents. They are mostly powerful poisons requiring careful usage.

QUESTIONS

1. What is the composition of cotton fiber? Why is it well suited for spinning? What condition is necessary for spinning quality?
2. How is mercerized cotton prepared?
3. How is artificial silk made?
4. What are the changes of retting?
5. What is the composition of hemp fiber?
6. How is wool cleaned? What is the structure of its fiber? What is its composition?
7. What is the source of silk fiber? What is its composition?
8. What is the source of modern dyes?
9. What is a direct dye? A substantive dye? A mordant?
10. What is meant by dry cleaning?
11. How you would remove paint or pitch stains? Ink stains? Rust spots? Grass stains? Blood stains? Fruit stains?
12. How can cloth be bleached?
13. What is lead white?
14. What are "driers"?
15. What is the composition of paints for metal surfaces?
16. How is varnish made?
17. How should painted or varnished surfaces be cleaned?
18. How is Portland cement made? What is its composition?
19. What are the chemical processes of setting of cement?
20. What is the composition of mortar?
21. What are the chemical changes in the making and setting of plaster?
22. State three ways in which insecticides act.
23. What is the composition of Paris Green?
24. How is lead arsenate prepared?
25. What is the objection to soluble compounds of arsenic in insecticides? How can their presence be prevented? What chemical change does it undergo on foliage?
26. What is a miscible oil? For what is it used?
27. Name two gaseous insecticides.
28. What is a fungicide?
29. How should Bordeaux mixture be prepared? Why should an excess of copper be avoided? How can it be corrected?
30. What is the purpose of using disinfectants?
31. Name three important disinfectants, stating the chemical nature of each?

EXPERIMENTS

CHAPTER I.

EXPERIMENT 1

Object:—To study the properties of elements, compounds, and mixtures.

Apparatus and Material:—Magnifying glass, magnet, test tubes, finely powdered iron, powdered sulphur, and dilute hydrochloric acid.

Method:—Part A. Secure some finely powdered iron and sulphur. Subject each of them separately to the following tests: (a) Note their color, odor, etc. (b) Examine with a small magnifying glass, noting the crystalline form. (c) Test with a magnet. (d) Place a small quantity in a test tube and add 5 c. c. of dilute hydrochloric acid.

Part B. Stir together 3 grams of the sulphur and 5 grams of the iron. Test the mixture in the four ways directed above.

Part C. Stir together a fresh portion of 3 grams of sulphur and 5 grams of iron. Place the mixture in a 6 inch test tube. Heat with a small flame. When the mass glows like a red hot coal, remove the tube from the flame. When the action is over, plunge the tube into some cold water in a beaker. Carefully pick out the fused mass from the broken glass, dry, and powder it. Test in the four ways indicated above.

Results:—What is the appearance of the sulphur in the first two cases? Is any sulphur visible after the mixture has been heated? What is the effect of the magnet in the three parts of the experiment? Of the hydrochloric acid? Does the iron still exist as such in parts B and C? Does the sulphur still exist as such in parts B and C? Is it easier to separate sulphur and iron when they are in a mixture before or after heating?

EXPERIMENT 2

Object:—To study examples of physical change.

Apparatus and Material:—Balance and weights, porcelain evaporating dish, water bath, magnifying glass, porcelain crucible, test tubes, funnel, sugar, iodine, alcohol, potassium iodide solution.

Method:—Part A. Weigh 5 grams of sugar, add to 25 c. c. of water, and stir until dissolved. Place the solution in a porcelain evaporating dish and evaporate to dryness upon a water bath. Take a small amount of the original sugar and also of the solid residue in the evaporating dish. Apply the following tests to them: Taste a portion, examine some with a magnifying glass, heat a little in a porcelain crucible.

Results:—Describe the results of these tests. Is there any difference between the two samples? Does the process of solution seem to have any effect upon the properties of the sugar?

Part B. Place a very small piece of iodine in a test tube. Heat the bottom of the tube gently in a flame and pass the vapors upon a cold surface, as the interior of a porcelain dish or an inverted funnel. Study both the original and the condensed (sublimed) materials. What is their color and general appearance? What is the effect of heat upon them? Are they soluble in a solution of potassium iodide or alcohol?

Results:—Is there any difference between the samples? Does the process of heating affect the iodine in any way?

EXPERIMENT 3

Object:—To study examples of chemical change.

Apparatus and Material:—Test tubes, crucible, crucible tongs, sugar and magnesium ribbon.

Method:—Part A. Place two grams of sugar in a clean 6 inch test tube. Hold the tube horizontally and heat slowly and carefully until the sugar begins to darken. Remove the tube from the flame and examine it carefully. Replace in the flame and heat strongly until no further change occurs. Note results. What products are formed?

Part B. Place 2 grams of sugar in a small crucible. Heat slowly and carefully, noting all the results. Describe the changes which occur.

Results:—Is there any difference between heating sugar in a test tube and in a crucible? If so, what is the most striking distinction? What is the essential difference in these two methods?

Part C. Take a small piece of magnesium ribbon about 1½ inches long. Grasp it with a pair of crucible tongs or forceps and light it in the flame of a burner. What is the result?

Results:—State at least two differences in the properties of the original and the resulting materials. Is there any difference between the light produced in this experiment and that from an ordinary electric bulb or a kerosene lamp?

EXPERIMENT 4

Object:—To learn the effect of heating a metal with and without air.

Apparatus and Material:—Porcelain crucible, stout iron wire, lead or tin or solder, powdered borax or calcined magnesia.

Method:—Part A. Place 5 grams of lead, tin, or solder in a porcelain crucible. Heat strongly until the metal is melted and stir continually with a stout iron wire. After the mass has become of uniform powdery texture throughout (homogeneous), allow the crucible and its contents to cool.

Part B. Place another 5 gram portion of the metal in a second crucible and cover the metal with a rather deep layer of borax powder or calcined magnesia. Heat until the metal is melted and stir for the same length of time as required in part A. Cool the crucible and remove the layer of magnesia.

Results:—Examine the contents of both crucibles and state the results of the experiment. Is there any marked difference in the properties of the two masses? What is the reason for such a difference? Which part of the experiment illustrates a physical change and which part a chemical change?

CHAPTER II.

EXPERIMENT 5

Object:—To show the presence of water in a series of substances.

Apparatus and Material:—Test tubes, uncooked potato, uncooked meat, clay and copper sulphate.

Method:—Place a small amount of uncooked potato, uncooked meat, clay, and copper sulphate in separate test tubes. Heat the tube containing the potato carefully in a horizontal position in the flame of the burner nearly to the point of blackening the potato. Withdraw the tube from the flame and examine the sides of the tube. Apply the same treatment to the other three tubes.

Results:—Is there any evidence as to the presence of water in any of the cases? State approximately the relative amounts of water present in each case, that is, large or small. State of what general classes of materials the examples chosen are typical.

EXPERIMENT 6

Object:—To show that water is formed by the burning of substances which contain hydrogen.

Apparatus and Material:—Beaker, candle, wood.

Method:—Hold a lighted candle under a glass full of cold water. After a minute or two, remove the candle and examine the bottom of the glass. If necessary, rub the forefinger over the glass to ascertain the result. Repeat the experiment by holding a cold surface of glass or metal over a piece of burning wood or the burner that is used as a source of heat in the laboratory.

Results:—What result is common to all of these tests? What conclusions can be drawn as to the burning of substances of plant and animal origin?

EXPERIMENT 7

Object:—To study the composition of natural waters.

Apparatus and Material:—Water bath, evaporating dish, several samples of natural waters.

Method:—Three students may work together in this experiment, one using rain water, another artesian well water, and a third using surface well water.

Fill a water bath half full of water, heat to boiling, and place an evaporating dish upon it. In the evaporating dish place some of the water to be tested, and evaporate 100 c.c. to dryness. Is there any residue or not? What is its nature? Moisten the end of the little finger, touch the residue, and taste the material. Result?

Dry the bottom of the dish, and heat slowly and carefully with the flame. Is there any change in the appearance of the material? Repeat these tests with each sample of water, or the three students may compare notes upon their respective samples.

Results:—State the two principal effects in each case. State the chief differences in the character of the samples. Which is the purer of the samples examined?

Note:—By careful work the student may determine the amount of total solids in water. Weigh the dish before and after the water is evaporated. The difference in weight is the amount of solids in the water taken.

EXPERIMENT 8

Object:—To show whether water aids chemical reactions.

Apparatus and Material:—Beaker, glass rod, baking soda, powdered tartaric acid.

Method:—Place 2 grams of baking soda and 2 grams of powdered tartaric acid in a glass. Mix the two solids intimately by stirring with a glass rod. Result? Add a drop of water to the mass. Result? Add more water gradually until there is no further action.

Results:—What effect did water have upon the chemicals? Is this reaction similar to that of baking powder? To Seidlitz powders?

EXPERIMENT 9

Object:—To show the effect of water upon the properties of substances.

Apparatus and Material:—Test tubes, crucible, powdered copper sulphate, powdered alum.

Method:—Heat a small amount of powdered copper sulphate in a test tube until all the water is driven off. Cool. Compare the appearance of the product with that of the original material. Add a single drop of water to the residue. What is the result?

Heat a small amount of powdered alum in a crucible until all water is driven off. Cool, remove the dry mass, and touch the substance to the tongue. Compare also the taste of the original material. Results?

Results:—Does water change any of the properties of these two substances?

EXPERIMENT 10

Object:—To show the effect of a metal, sodium, upon water.

Apparatus and Material:—Large beaker or wide mouth bottle, glass plate, paper, sodium metal, filter paper, red litmus paper.

Method:—Part A. Place about 100 c.c. of distilled water in a large beaker or wide mouth bottle. Take a piece of sodium not larger than a small pea and drop it upon the water, immediately covering the container with a glass plate or a piece of paper. Stand back from the apparatus just far enough to see the reaction. Wait for the slight explosion which usually occurs soon after the action stops. Describe all that has happened in the experiment.

Part B. Continue the experiment. Place a small piece of filter paper, the size of a quarter, on the surface of the water. Before the paper sinks, carefully drop a small piece of sodium, the same size as used above, upon the paper. Cover the glass, stand back, and note the result.

Results:—Is there any difference in the results of the two parts of the experiment? If so, to what is this due? What is probably the cause of the bright color seen in part B? If sodium reacts so violently with water, is it a safe chemical to leave carelessly in the open air? Why? How is the metal protected from the air? What other purpose is there in protecting the metal? Does sodium seem to have any effect upon the fingers? Why?

Part C. Place a piece of red litmus paper in the liquid from the above experiments. Also cautiously rub some of the liquid between the thumb and forefinger. Again very carefully touch the tip end of the tongue to the finger moistened with the liquid. Repeat these tests with distilled water.

Results:—State the results. What is the conclusion in regard to the effect of sodium upon water?

Caution:—Do not handle sodium with wet hands or with wet forceps. Do not put sodium into the waste jar. Return all extra pieces of this metal to the instructor.

EXPERIMENT 11

Object:—To prepare oxygen.

Apparatus and Material:—8-inch hard glass test tube, pneumatic trough, 3 bottles, crucible, cardboard, potassium chlorate, manganese dioxide.

Method:—Weigh 10 grams of potassium chlorate and 10 grams of manganese dioxide, mix thoroughly, and place in an 8 inch test tube (preferably of hard glass). Arrange the apparatus as shown in Figure 11. Fill the pneumatic trough with water until the shelf is just covered. Fill three bottles full of water, cover each with a small glass plate or cardboard, invert them in the trough, and remove the cover.

Heat a small amount of the mixture of equal parts of chlorate and manganese dioxide in an open crucible. If there is no explosion it is safe to proceed with the experiment. Heat the test tube gently at first, gradually increasing the temperature until there is a steady flow of gas issuing from the outlet of the generator. Then place a bottle over the bubbles of gas and displace all the water in the bottle with the gas. Fill the other two bottles with the gas in the same way. Now remove the end of the delivery tube from the water. Why? Also take each bottle as it is filled and cover with a wet filter paper. Proceed to the next experiment immediately.

EXPERIMENT 12

Object:—To demonstrate the properties of oxygen.

Apparatus and Material:—Piece of chalk hollowed at one end, picture wire, wood splinter, powdered sulphur.

Method:—Part A. Into one bottle of oxygen prepared in the previous experiment dip a glowing stick of wood or wax taper. Result? Remove the stick, extinguish the flames except a spark, and repeat as many times as possible, gradually lowering the stick more and more into the bottle. What is the effect of the gas upon the glowing stick? Does the gas itself burn? What property of oxygen does this illustrate?

Part B. Place a small amount of sulphur in a deflagrating spoon or piece of hollowed chalk. Hold in the flame until the sulphur begins to burn, then lower into the second bottle of oxygen. Results? Is there any change in the flame? Describe it. Brush a little of the gas cautiously toward the nose. What does it smell like?

Part C. In the third bottle place enough water to cover the bottom. Take a piece of picture wire 6 inches long and unwind one end of it. Dip this end in melted sulphur, and while this is burning, lower it into the bottle of oxygen. Results? Why is the iron tipped with burning sulphur? Of what use is the water in the bottom of the bottle?

Results:—What do these experiments show in regard to the properties of oxygen? Why is combustion more active in an atmosphere of the pure gas than in the air?

EXPERIMENT 13

Object:—To study the construction of the Bunsen burner.

Apparatus and Material:—The Bunsen burner, a piece of bright iron, match.

Method:—Take the Bunsen burner apart. Draw a sketch of each part in the same relative position it occupies in the burner. Put the burner together again, and connect with the gas supply.

Close the holes in the bottom of the burner, turn on the gas, and hold a lighted match slightly below the mouth of the burner. Result? Open the holes carefully until the luminous flame just disappears. Result? Open the holes as far as possible. Result? Now close the holes to the position where a small luminous cone is left in the flame. Place a cold surface, as a piece of bright iron or porcelain, upon the cone for a minute. Result?

Introduce quickly into the center of the non-luminous or Bunsen flame just above the top of the burner the head of a match. Results?

Results:—What is the difference in the character of the flame when the holes near the bottom of the burner are closed and when they are open? To what is this difference due? What is the effect of too much air? Of too little? Is there any disagreeable effect attending this latter feature? What does the test with the match show? Where is the hottest part of the flame?

EXPERIMENT 14

Object:—To demonstrate the meaning of kindling temperature.

Apparatus and Material:—Bunsen burner, wire gauze, match.

Method:—Hold a piece of iron wire gauze about 3 inches above the mouth of a Bunsen burner. Open the holes of the burner, turn on the gas, and lower a lighted match from above down to the center of the gauze. Result? After a few minutes if the gas does not take fire below the gauze, light it.

Allow the gauze to cool. Bring it down upon the non-luminous flame of the burner until the gauze is three inches above the top of the burner. Results? Hold the gauze in place until it becomes red hot. Results?

Results:—In the first instance, why does the gas not burn below the gauze? In the second part of the experiment, why does the gas not burn above the gauze until the latter is red hot? What special type of lamp makes use of the principle that is involved in this experiment?

EXPERIMENT 15

Object:—To prepare hydrogen.

Apparatus and Material:—A gas generator (see Figure 15), granulated zinc, commercial hydrochloric acid.

Method:—Arrange an apparatus similar to that shown in Figure 16. Place in the flask about 25 grams of granulated zinc. Add water through the thistle tube until the bottom of the latter is immersed. Then add a small amount of commercial hydrochloric acid until the gas is evolved rapidly. Allow considerable gas to escape before collecting any. Why?

Fill two bottles with water and invert in the trough in the same manner as in the preparation of oxygen. Fill these with hydrogen and allow them to remain in the trough until they are needed for the next experiment. Proceed immediately to test the properties of hydrogen.

EXPERIMENT 16

Object:—To demonstrate the properties of hydrogen.

Apparatus and Material:—Hydrogen gas, wood splinters, match.

Method:—Grasp the bottom of one of the bottles of the gas and keep it in this inverted position. Thrust a burning splinter of wood up into the middle of the bottle of gas (Figure 17). Does the gas burn? Does the splinter burn?

Place the mouth of the second bottle of hydrogen over the mouth of an upright bottle of air. Hold the bottles together and reverse their positions. After a minute apply a lighted match to the lower bottle. Result? To the upper. Result?

Results:—Does hydrogen burn or does it support combustion? Is it lighter or heavier than air? Is its mixture with air explosive? Is it safe to have lights near a hydrogen generator?

Caution:—Keep all flames at least three feet away from the flask in which hydrogen is being prepared.

CHAPTER III.

EXPERIMENT 17

Object:—To show some effects of the rusting of iron in the air.

Apparatus and Material:—100 c.c. or 200 c.c. graduate, clamp, pint mason jar, muslin cloth, steel wool or clean iron filings, wood splinter.

Method:—Force a wad of steel wool or a quantity of clean iron filings tied in a muslin bag about half way up a graduated tube of 100 or 200 c.c. capacity. Wet the iron and clamp the tube with its open end down in a vessel of water. The level of water inside the tube should be within the graduations. If not, remove the tube, add water to it, cover with the hand and replace in the water. Read the level of the water inside the tube and allow the experiment to stand undisturbed for two or three days. Occasionally feel the tube near the iron mass. Again read the level of the water. Thrust a glowing splinter of wood up into the gas remaining in the tube. Results? Remove the iron or steel and examine carefully.

Results:—What are the results? Is heat evolved or absorbed? To what is the change in the iron due? What does the change in the volume show? Explain the effect upon the glowing stick.

EXPERIMENT 18

Object:—To show whether water exists in the atmosphere.

Apparatus and Material:—Watch glasses, calcium chloride.

Method:—Several students may do this experiment together. Weigh upon each of several watch glasses about 5 grams of calcium chloride. Place the different glasses in different parts of the room, as near a window, or the sink, or a radiator, or in a cupboard. Allow them to remain in these positions for a day. Examine the glasses, weigh again, and state the results. In case nothing definite is shown, allow the glasses to remain exposed for another day.

EXPERIMENT 19

Object:—To show whether carbon dioxide exists in the atmosphere.

Apparatus and Material:—50 c.c. beaker, glass tubing, limewater.

Method:—Several students may do this experiment together in a manner similar to experiment 18. Use a 50 c.c. beaker half full of perfectly clear limewater instead of the glass with calcium chloride. After a day's exposure in the different positions, examine the beakers and their contents. Results?

Place in a 50 c.c. beaker about 25 c.c. of perfectly clear limewater, secure a clean piece of glass tubing, and blow into the liquid for a few minutes.

Results:—Is there any similarity between this result and that in the first part of the experiment? What is the connection between the two parts?

EXPERIMENT 20

Object:—To study the properties of acids.

Apparatus and Material:—Test tubes, glass rods, dilute hydrochloric acid, dilute sulphuric acid, strong acetic acid, red and blue litmus paper, zinc, limestone, chalk, or marble.

Method:—Half fill three test tubes with dilute hydrochloric acid, sulphuric acid, and strong acetic acid respectively. Dip a clean glass rod into each acid and carefully taste it. Dip the rod a second time into the acid and transfer a drop to both red and blue litmus paper. Results? Place a small piece of zinc in each tube. If no action results, warm gently. Hold a lighted match over the mouth of the test tube. Results? Into fresh portions of the acids place a small piece of limestone, chalk, or marble. Hold a glass rod which has been dipped in clear limewater in the escaping gas. Results?

Results:—Describe by a single word the taste of all the acids tested. The effect of acids upon litmus paper is quite characteristic. What conclusion can be drawn from the test? What substance is evolved from the action of the metals upon acids? Has this been shown in any previous experiment? What is the gas liberated from the calcium carbonate by the acids? What general statement can be made, then, concerning the properties of acids?

EXPERIMENT 21

Object:—To study the properties of bases.

Apparatus and Material:—Test tubes, glass rods, sodium hydroxide, potassium hydroxide, ammonium hydroxide, limewater, red and blue litmus paper.

Method:—Prepare dilute solutions of sodium and potassium hydroxides by adding a very small piece of each to test tubes half full of water. Also half fill a test tube of dilute ammonium hydroxide and one with limewater. Apply the following tests to these materials. Rub a little of the liquid between the fingers and describe the feeling. Barely moisten a glass rod with each of the liquids and very cautiously taste them. Again dip the glass rod in each liquid separately and touch a piece of red and blue litmus paper.

Results:—Describe the results of the testing of these liquids. Compare the action upon litmus paper with that of acids upon such test paper. What is the most striking result of these tests?

EXPERIMENT 22

Object:—To study the properties of salts.

Apparatus and Material:—Test tubes, sodium chloride, potassium sulphate, ammonium chloride, barium chloride.

Method:—Prepare dilute solutions of sodium chloride, potassium sulphate, ammonium chloride, and barium chloride. In the same manner as in the tests for acids and bases carefully taste each liquid. Also test the action of each upon both kinds of litmus paper.

Results:—Is there any general characteristic of taste as in the case of the acids and bases? How does the action of these salts upon litmus compare with the action of acids and bases upon litmus?

EXPERIMENT 23

Object:—To study the reaction of common substances.

Apparatus and Material:—Lemon juice, vinegar, sour milk, borax, soap, washing soda, sugar, cream of tartar, baking soda, sweet milk, litmus paper.

Method:—Apply the litmus test to the substances named above.

Results:—Tabulate the results under the three heads of acid, alkali, and neutral reactions.

EXPERIMENT 24

Object:—To study the reaction of acids and alkalies.

Apparatus and Material:—Sodium hydroxide, hydrochloric acid, litmus paper.

Method:—Place 50 c.c. water in a 100 c.c. evaporating dish and add a small piece of sodium hydroxide. When the alkali is dissolved, add hydrochloric acid drop by drop, constantly testing with litmus paper until the solution just reacts acid. Evaporate to dryness by heating over a wire gauze, finally heating the dish until the yellow color disappears. Test a portion of the residue with litmus. Result? Taste a little of the residue.

Results:—What is the effect of the residue upon litmus? What does the residue taste like? What is such a reaction called? Is this an appropriate name?

EXPERIMENT 25

Object:—To demonstrate the properties of nitric acid.

Apparatus and Material:—Test tubes, white quills, wood or silk, copper foil or wire, chalk, nitric acid.

Method:—Place a few fragments of white quills, or wool, or silk, in a test tube. Add enough dilute nitric acid to cover the material and warm gently. Pour off the acid and wash the substance with water. Result?

Place a short strip of copper foil or wire in a test tube. Add nitric acid and warm gently until the action starts. Describe all that takes place.

Place a small amount of chalk in a test tube. Add a small amount of dilute nitric acid. Results?

Results:—Describe all the results of the above experiments. Is nitric acid an active compound or not? Should one use care in working with the acid?

EXPERIMENT 26

Object:—To demonstrate the properties of ammonia gas.

Apparatus and Material:—200 c.c. flask, 3 dry bottles, deep dish or tin, wood splinters, concentrated ammonium hydroxide, hydrochloric acid, sodium hydroxide solution, litmus paper.

Method:—Place 50 c.c. of concentrated ammonium hydroxide in a 200 c.c. flask. Heat gently to drive off the gas. Fill three bottles separately with the gas by holding the empty bottles directly over the mouth of the flask. Why does the ammonia replace the air?

Plunge the mouth of one of the bottles of gas under water. Allow this to stand for some time and proceed with the remainder of the experiment. Slowly introduce into the second bottle a lighted splinter of wood. Describe the behaviour of the gas on the instant when it comes in contact with the flame. Does the gas burn? Does it support combustion?

Pour a few drops of strong hydrochloric acid into an empty warm dry bottle. Cover with a glass plate, invert, and stand upon the third bottle of ammonia gas. Remove the glass plate and hold the bottles together by grasping them firmly about their necks. Results? Is there any evidence of chemical action? Is heat evolved? Allow the white product to settle, remove some, and warm in a test tube with a little sodium hydroxide solution. What is the gas given off? What was the white product?

Return to the first bottle of gas which is standing in water. Place a glass plate under the mouth of the bottle and invert it with the water remaining in the bottle. Test it with a piece of litmus paper. Result?

Results:—Is ammonia gas soluble in water? To what degree? How is this shown? How does the water solution affect litmus paper? What other experiment gave a similar result? What is the relation of ammonia to combustion? What is the reaction with hydrochloric acid?

EXPERIMENT 27

Object:—To study the properties of nitrates.

Apparatus and Material:—Test tube, iron pan, sodium nitrate, sulphate of iron, concentrated sulphuric acid, charcoal, powdered potassium nitrate.

Method:—Place a small amount of sodium nitrate solution in a test tube. Add a crystal of ferrous sulphate and shake the mixture until the sulphate is dissolved. Now add cautiously 2 or 3 c.c. of strong sulphuric acid. Incline the tube so that the acid will flow down to the bottom of the solution without mixing with it. What is the result?

Heat a piece of charcoal in the burner. Lay it upon an iron pan and very carefully sprinkle powdered potassium nitrate upon the hot surface. Stand back when the action begins.

Results:—Observe and describe the reaction. Is it violent? Is it rapid? What is the color of the flame and the effect upon the charcoal. What causes the action? What rather common substance deflagrates when made to react in a similar manner?

CHAPTER IV.

EXPERIMENT 28

Object:—To prepare chlorine.

Apparatus and Material:—Gas generating flask (see Figure 23), 3 dry bottles, manganese dioxide, concentrated hydrochloric acid.

Method:—Arrange an apparatus like that shown in Figure 24. Place in the flask 5 grams of manganese dioxide (lumps) and add through the funnel 20 c.c. concentrated hydrochloric acid. Warm the flask gently and fill three dry bottles with the chlorine. Keep the bottles stoppered until ready to use. Pass the gas from the generator into 15 c.c. cold water in a test tube for 5 minutes. When through, disconnect the apparatus at once and wash the manganese dioxide which remains with two portions of water.

Caution:—Avoid inhaling chlorine. If some of the gas has been accidently inhaled, breathe ammonia gas very cautiously after removing the stopper from a bottle of ammonia water.

EXPERIMENT 29

Object:—To show the properties of chlorine.

Apparatus and Material:—Splinter of wood, dyed calico, newspaper, paper with ink writing.

Method:—What is the color and the odor of the gas? (Do not smell the gas directly. Enough generally escapes into the room to give the test.) Thrust a lighted splinter of wood down into a bottle of the gas. Does the gas burn or does it support combustion? Put into a bottle of the gas a small piece of wet dyed cloth, a small piece of dry dyed cloth, a paper with print and a paper with ink. Allow to remain 15 minutes. Results? Into another bottle of chlorine pour some powdered antimony which has previously been slightly heated.

Results:—Is chlorine an active element? What evidence shows this? In the bleaching experiment, what factor seems to be essential in order to accomplish the bleaching?

EXPERIMENT 30

Object:—To prepare hydrochloric acid and study its properties.

Apparatus and Material:—Gas generating flask (see Figure 24), 2 dry bottles, common salt, dilute sulphuric acid, red and blue litmus paper.

Method:—Arrange an apparatus like that in Figure 23, but omitting the wash bottle. Place about 15 grams of common salt in the flask and add enough water to just cover the bottom of the thistle tube. Now add about 25 c.c. of dilute sulphuric acid (1 part acid and 1 part water) and heat gently. Collect two dry bottles of the gas by downward displacement of air. Into one of the jars place small pieces of moistened blue and red litmus paper. Place the second bottle mouth down in a dish of water. Test the reaction of the water solution with pieces of red and blue litmus paper.

Results:—Describe the results of the experiment. Is the gas very soluble in water? Does the water solution have the same reaction as the gas itself?

EXPERIMENT 31

Object:—To study the bleaching action of bleaching powder.

Apparatus and Material:—2 small beakers, bleaching powder, dilute sulphuric acid, dyed calico.

Method:—Take two small beakers; in one place some dilute sulphuric acid and in the other some bleaching powder and water. Saturate a piece of dyed calico in the acid; then dip it into the bleaching powder paste. If necessary, repeat this operation several times. Finally wash the cloth in a basin of water.

Results:—What happens to the color in the cloth? Does there seem to be a gas liberated from the powder by the action of the acid? What is it? How can you prove it?

EXPERIMENT 32

Object:—To show the presence of chlorides in water.

Apparatus and Material:—Dilute solution common salt, dilute silver nitrate, drinking water, nitric acid.

Method:—Prepare a dilute solution of common salt. To 10 c.c. of this add 3 drops of nitric acid and about 5 c.c. of dilute silver nitrate solution. Warm the mixture slightly and shake strongly. What is the character of the precipitate? Secure a sample of drinking water. To about 25 c.c. add 3 drops of nitric acid and 5 c.c. of silver nitrate and proceed as above. If no definite result is shown, evaporate 100 or 200 c.c. of the drinking water to a small bulk and repeat the test. Results?

EXPERIMENT 33

Object:—To study the degree of chemical affinity of one element for another.

Apparatus and Material:—6-inch test tubes, dilute solutions of potassium iodide and potassium bromide, chlorine water, chloroform.

Method:—Prepare a dilute solution of potassium bromide and place 10 c.c. in a 6 inch test tube. Add about 2 c.c. of the chlorine water prepared in a previous experiment and shake the mixture well. Result? Now add about 2 c.c. of chloroform to the mixture and again shake well. Result? Repeat the test, but use a dilute solution of potassium iodide instead of the potassium bromide. Result?

Results:—Does this experiment confirm your conclusion that chlorine is or is not an active element? What were the substances liberated by the action of the chlorine water upon the potassium salts taken? If chlorine is able to displace an element from its compound with another element, which is the more active chemical substance, the chlorine or the displaced element?

EXPERIMENT 34

Object:—To study the effect of heating sulphur.

Apparatus and Material:—6-inch test tubes, powdered sulphur.

Method:—Fill a test tube ⅓ full of sulphur, hold it at an inclined angle and heat carefully. As the temperature gradually increases, note all the changes that occur. What happens to the sulphur? What is the color of the new form? Is it thick or thin? Pour a drop into water. What is the color of the product? Is it soft or hard? Now heat the sulphur further. What happens? Heat still more until the sulphur begins to boil; then pour it into cold water. Result? What is the color of the product? Is it hard or soft? Elastic or brittle? Keep this sample for several weeks, if necessary, noting any changes that occur upon standing. Results?

EXPERIMENT 35

Object:—To study the properties of sulphur dioxide.

Apparatus and Material:—Piece of crayon with hollowed end, dry bottles, powdered sulphur, red and blue litmus paper, pink flower or old straw.

Method:—Place about 1 gram of sulphur in a hollowed crayon. Heat in the flame until it burns briskly and then lower it into a bottle of air. Allow the sulphur to burn as long as it will, covering the bottle with a cardboard. What are the products of this action? Lower pieces of moistened red and blue litmus paper into the bottle. Result? Moisten a pink flower or piece of old straw, place in the bottle, and allow to remain there for an hour or more. Result?

EXPERIMENT 36

Object:—To study the properties of sulphuric acid.

Caution:—Never pour water into the acid.

Apparatus and Material:—2 beakers, fine glass rod, strong sulphuric acid, red and blue litmus paper, barium chloride solution, sugar, boiling water.

Method:—Prepare a small amount of dilute sulphuric acid as follows: Place 50 c.c. of water in a 100 c.c. beaker and add slowly and cautiously 10 c.c. of strong sulphuric acid. Note all that happens. Place the hand upon the outside of the beaker in order to answer this question.

(1) Dip small pieces of red and blue litmus paper into the diluted acid. (2) Write with a fine glass rod, using the diluted acid, upon white paper. Dry the paper carefully over a low flame. (3) Take a few c.c. of the diluted acid and add some diluted barium chloride solu-

tion. Warm until a definite result is secured. (4) In a beaker of about 150 c.c. capacity place 25 grams of sugar. Add 30 c.c. of boiling water and place the beaker upon a large plate or piece of old paper. VERY CAREFULLY add 30 c.c. of strong sulphuric acid, standing as far back as possible from the apparatus.

Results:—Describe all the results of the different tests. In part (4) what is the chief substance produced? What characteristic property of sulphuric acid does this reaction illustrate?

EXPERIMENT 37

Object:—To study the properties of hydrogen sulphide.

Apparatus and Material:—Gas generating apparatus (see Figure 21), 2 dry bottles, ferrous sulphide, dilute hydrochloric acid, litmus paper, wood splinter, lead nitrate solution.

Method:—Arrange an apparatus similar to that illustrated in Figure 21. In the inner tube place lumps of ferrous sulphide. In the outer tube or bottle place dilute muriatic acid (1 part acid and 1 part water). Lower the tube into the bottle, open the stop cock, and collect two bottles of the gas which is liberated by downward displacement of air. In the first bottle pour about 15 c.c. water and shake. Note the action of the water upon the gas. Also test the reaction of the water solution upon litmus paper. In the second bottle lower a lighted candle or splinter of wood. Does the gas burn or does it support combustion? Bring a cold surface over the flame. Result? Pass the gas from the generator directly into a solution of lead nitrate. Result?

Results:—Is the gas soluble in water? What is its color and odor? What is its effect upon the solution of lead nitrate?

EXPERIMENT 38

Object:—To prepare amorphous carbon.

Apparatus and Material:—Test tubes and crucibles, bits of wood, ground bone, starch, and straw.

Method:—Fill an old test tube about ⅓ full of bits of wood. Hold the tube horizontally and heat. While continuing the heating, bring a burning match to the mouth of the tube. Examine the residue in the tube. Heat a small amount of ground bone, starch, or straw in separate crucibles or on crucible covers. After moderate heating, continue the ignition for some time.

Results:—State all the results of the experiment. How does the residue in the test tube compare with the material from which it was prepared? What result is obtained upon the moderate heating of the different materials in the crucibles? Upon prolonged heating?

EXPERIMENT 39

Object:—To study the properties of carbon.

Apparatus and Material:—Iron dish with cover, hard glass tube, powdered wood or animal charcoal, hydrogen sulphide water, litmus solution, or brown sugar solution, powdered charcoal and copper oxide.

Method:—Part A. Heat some powdered wood or animal charcoal for five minutes in a covered iron dish. Cool and add 2 c.c. of the material to 5 c.c. of hydrogen sulphide water. Shake thoroughly and filter. Compare the odor of the filtrate with that of the original solution taken. Result? Add 2 c.c. of the prepared charcoal to 5 c. c. of litmus solution. Boil and filter. If the litmus solution is not available use 5 c.c. brown sugar solution.

Part B. Take a piece of hard glass tube 10 inches long, heat in the center and draw out into two ignition tubes. Place in one a mixture of 1 part powdered charcoal and 5 parts of black copper oxide sufficient to give a layer about 1 inch in length. Heat strongly for about 5 minutes. Cool and pour the residue upon a piece of white paper.

Results:—What property of carbon do the tests in part A demonstrate? In part B what is the new substance formed in the tube? What name is applied to such reactions.

EXPERIMENT 40

Object:—To prepare carbon dioxide and study some of its properties.

Apparatus and Material:—Gas generating flask (see Figure 16), 3 clean dry bottles, marble or limestone, hydrochloric acid, lime water, wood splinter.

Method:—Arrange an apparatus similar to that shown in Figure 16. Carefully place a few pieces of broken marble or limestone in the flask. Add through the tube enough dilute hydrochloric acid to cover the bottom of the tube. Collect the gas that is evolved by downward displacement of air. Into one bottle of carbon dioxide add a few c. c. of clear limewater and shake the bottle. Results? Into a second bottle of the gas lower a lighted candle or splinter of wood. Does the gas burn or does it support combustion? Into a clean bottle of air lower a lighted splinter of wood, allow to remain there for a minute or two, remove and add a few c.c. of clear limewater to the bottle. Shake and note the result. Is there any relation between these two experiments? Blow into a few c.c. of clear limewater in a test tube.

Result? Is there any relation between this test and the others? Continue the blowing through the limewater until a second result is seen. What is the cause of this?

CHAPTER V.

EXPERIMENT 41

Object:—To study a characteristic test for sodium and potassium.

Apparatus and Material:—Fine iron wire, powdered common salt, powdered potassium nitrate, a crystal of potassium dichromate.

Method:—Part A. Secure some clean fine iron wire. Take a piece about 6 inches long and bend one end into a loop about 1/8 inch in diameter. Heat this end in the non-luminous flame of a burner until there is no decided color tinging the flame. Dip the loop, while hot, into some powdered salt and again heat in the flame. Repeat, holding near the flame a small bright red object, as a clear crystal of potassium dichromate.

Part B. Take another clean piece of iron wire, burn as before, and repeat the experiment, using potassium nitrate in the loop instead of sodium chloride. If a piece of blue glass is available, hold it in front of the flame while making the test.

Results:—State all the results of the experiment.

NOTE:—The student might at this time repeat or review the experiments, numbers 10, 21, and 24, upon the action of sodium with water, the properties of bases and neutralization.

EXPERIMENT 42

Object:—To ascertain the properties of limestone.

Apparatus and Material:—Test tubes, porcelain crucible, hydrochloric acid, litmus paper.

Method:—Examine a small piece of limestone, observing its structure, hardness and color. Powder some and try to dissolve a little in water. Test the water and decide whether the stone is soluble or not as follows: Filter off a portion of the clear solution and evaporate to dryness. Is there any residue? Try to dissolve some limestone in hydrochloric acid. Heat another portion to as high a temperature as possible in a porcelain crucible. Cool. Observe its color, structure, and hardness. Add a little water. Test with litmus.

Results:—State the results of all the tests applied to the limestone. Is it affected by heat? What is the product formed?

EXPERIMENT 43

Object:—To study the properties of quicklime.

Apparatus and Material:—Beaker, glass tube, porcelain dish, quicklime, litmus paper.

Method:—Part A. Secure a piece of quicklime which has not been slaked about as large as an English walnut. Describe its appearance. Add water to the lime cautiously, drop by drop, until there is evidence of a reaction. Describe the appearance of the product. Add enough water to thoroughly slake the lime and finally enough to make a thin paste. Stir the mixture well and filter off some of the liquid. Test with both kinds of litmus paper. Evaporate a small amount to dryness on a porcelain dish. Taste the liquid or residue in the dish. Blow through a clean glass tube into another portion of the clear limewater.

Results:—Does water react chemically with quicklime? What evidence shows this? Is the slaked lime soluble in water? Is the reaction acid, alkali, or neutral? What happenes when the breath is blown through the limewater? What happens if this is continued for some time? What is the significance of this experiment to agriculture? Review Experiment 19.

Part B. Place a small piece of quicklime in a tin dish and allow it to be exposed to the air over night. Examine the product. Add a small amount of hydrochloric acid to it carefully. Then add more acid until no more lime dissolves.

Results:—Does this product resemble that from the water slaking of lime? What is the gas liberated by the addition of the acid? How can this be proved? If a lime of good quality practically all dissolves in acid, is this sample of good quality?

EXPERIMENT 44

Object:—To study the cause of the hardness of waters.

Apparatus and Material:—250 c.c. glass stoppered bottle, test tubes, dilute calcium chloride solution, limewater, natural water, soap solution.

Method:—Part A. Place 10 c.c. of dilute calcium chloride solution in a 250 c.c. glass stoppered bottle. Dilute to 100 c.c. with distilled water. Add 2 c.c. of castile soap solution at a time and shake constantly until a lather is formed which persists for 5 minutes. Describe the results. Is there any difference in the sound of the liquid as it is shaken before and after an excess of soap is added?

Part B. Take 2 c.c. of perfectly clear lime-water and dilute to 10 c.c. Blow through the liquid for 5 or 10 minutes and filter. If necessary, filter a second time to secure a clear filtrate. What substance is now present in the solution? Divide the solution into two parts. Boil one part for about one minute. Result? To the second add a drop or two of soap solution and shake the liquid as before.

Result? Add the same amount of soap solution to the boiled portion and shake. Result? What is the difference in the behavior of the two portions? If necessary add more soap solution to the unboiled portion, a drop at a time, and with constant agitation. Result?

Part C. Repeat the experiment using a sample of water of direct interest to the student. Take 100 c.c. portions and add soap solution until the lather persists, trying both boiled and unboiled water.

Results:—What two substances apparently react with soap and prevent the latter from giving its characteristic suds in water? What is the name applied to this characteristic action? Is it possible to destroy one of these causes by boiling? Is the sample of natural water tested softened by boiling? Is soft water desirable in the home? Why?

EXPERIMENT 45

Object:—To show the effect of certain metals upon salts of other metals.

Apparatus and Material:—Test tubes, iron wire, zinc strips, solutions of copper sulphate and lead acetate, hydrochloric acid.

Method:—Part A. To a solution of copper sulphate add a few drops of hydrochloric acid. Clean an iron wire by rubbing it with a cloth dipped in hydrochloric acid. Immerse the clean iron wire in the copper solution and allow the whole to stand for some time. Remove the wire from the solution and rub the finger along it.

Results:—Describe all the results of the test. What is the black substance? How can it be proved? What becomes of the iron?

Part B. Fill a beaker nearly full of dilute lead acetate solution. Suspend a strip of clean metallic zinc in the solution. Allow the experiment to stand undisturbed for some time.

Results:—Describe all the results of the experiment.

EXPERIMENT 46

Object:—To compare the heat conductivity of metals.

Apparatus and Material:—Iron wire, copper wire, forceps, burner.

Method:—Secure a piece of iron wire and of copper wire, as near as possible of the same gauge. Cut pieces exactly 6 inches long. Hold an end of the copper wire in one hand and an end of the iron wire in the other hand. Place the other ends of the wires in the flame of a burner and continue there until a definite result is secured. Grasp the end of each wire with a pair of forceps and hold in the hottest part of the Bunsen flame. Result? If nothing definite is shown by this test, repeat if possible with a blast lamp.

Results.—Which metal conducts heat better? Is there any change in that portion of the wire heated directly in the flame? Which metal is the more easily fusible? Which metal oxidizes the more readily? Is any practical use made of this property in everyday life?

EXPERIMENT 47

Object:—To show some tests for copper salts.

Apparatus and Material:—Copper sulphate solution, ammonium hydroxide, potassium ferrocyanide, hydrogen sulphide gas.

Method:—Dissolve a small amount of copper sulphate in water. To the clear solution add ammonium hydroxide gradually, but finally in excess. To a solution of copper sulphate add a few drops of potassium ferrocyanide solution. Pass hydrogen sulphide into a dilute soltion of copper sulphate.

Results:—State the results of the three tests.

EXPERIMENT 48

Object:—To prepare sulphate of iron.

Apparatus and Material:—400 c.c. beaker or flask, clean iron nails, dilute sulphuric acid, ammonium hydroxide, nitric acid, tannin solution, young growing plants of small grains or weeds.

Method:—Part A. Place 20 grams of clean iron nails in a 400 c.c. flask or beaker. Add 20 c.c. dilute sulphuric acid (1 part acid to 5 parts water) and warm gently until the evolution of gas ceases. Pour off the clear solution into a clean beaker, add 2 c.c. dilute sulphuric acid and boil. When the liquid becomes half the volume of the original allow to cool. After the crystals of ferrous sulphate have separated, pour off the liquid from them and dry in the air for a short time.

Part B. Test the properties of the iron sulphate by dissolving some of it in water and making the following tests upon the solution. To one portion add a few drops of ammonium hydroxide and boil. To a second portion add 2 drops of nitric acid and boil, then cool and add ammonium hydroxide as before. These two precipitates illustrate the ferrous and ferric type of compounds. To another portion of the ferrous sulphate add a few drops of tannin solution. If young growing plants of weeds or the small grains are available, sprinkle some of the solution of ferrous sulphate upon them.

Results:—State the results of the different tests. What common substance does the mixture of ferrous sulphate and tannin resemble? What is the effect of the ferrous sulphate upon the plants? What is this compound used for on the farm.

EXPERIMENT 49

Object:—To show the properties of zinc.

Apparatus and Material:—Bunsen burner or blast lamp, forceps, zinc foil, sodium hydroxide, zinc sulphate, hydrogen sulphide.

Method:—Grasp a piece of zinc (preferably the foil) with a pair of forceps. Hold it in the flame of a blast lamp, if one is available. Result? It is better to hold the zinc over an asbestos sheet or an iron pan.

To a solution of zinc sulphate add some sodium hydroxide. Result? Add an excess of the sodium hydroxide Result? Now pass hydrogen sulphide into this solution.

Results:—What is a characteristic property of the second precipitate? What use is made of zinc compounds in commerce on account of this property?

EXPERIMENT 50

Object:—To show the properties of magnesium.

Apparatus and Material:—Test tubes, magnesium ribbon, hydrochloric acid, dilute sulphuric acid, dilute nitric acid.

Method:—Repeat the experiment of burning a piece of magnesium ribbon (See Experiment 3,C.). Place small pieces of magnesium ribbon in three separate test tubes. To one add a small amount of dilute hydrochloric acid; to the second add dilute sulphuric acid; and to the third add a small amount of dilute nitric acid.

Results:—Is any gas given off? If so, what is it? How can the nature of the gas be proved?

CHAPTER VI.

EXPERIMENT 51

Object:—To show the presence of water in plants.

Apparatus and Materials:—A tall, narrow can, such as a tin fruit can, a test tube, a one-holed cork to fit the tube, a piece of glass tubing to fit the cork, fresh grass or other soft plant tissue.

Procedure:—Bend the tubing through about 120° near one end and insert the short end through the cork. Fix the cork firmly in the test tube and fasten the latter upright in the can. Nearly submerge the test tube in water, first filling it with finely cut grass tightly packed. Now boil the water.

Results:—Does any liquid drop from the tube? Test it by letting a drop fall on a crystal of copper sulphate previously heated to whiteness. What is it? Why was the copper sulphate heated?

EXPERIMENT 52

Object:—To show the production of water and carbon by heating carbohydrates.

Apparatus and Materials:—Common sugar. The apparatus of Experiment 51, with the exception of the tin can.

Procedure:—Place a little of the sugar, previously dried in the oven, in the test tube. Connect the bent glass tube. Heat the sugar gradually with a flame.

Results:—Observe the melting and darkening of the sugar. Caramel is formed. At last decomposition begins. Notice the smoky products forming in the tube. What is the black material at the bottom of the tube? Does a liquid drop from the extended arm? Test it with heated copper sulphate as in Experiment 51. How was it formed?

EXPERIMENT 53

Object:—To compare the amounts of water in different plant tissues.

Apparatus and Materials:—A balance weighing to 500 grams, two shallow one pint tin dishes, a drying oven regulated to 100° C., whole corn, green corn fodder or corn silage.

Procedure:—Number the dishes 1 and 2 with a soft pencil and dry them. Add weights to balance dish 1 and weigh into it 100 grams of cracked or ground corn. Weigh 100 grams of green fodder or silage into dish 2. Record as weights A the weights of the dishes and materials. Dry in the oven for 24 hours, remove and weigh as soon as cool. If possible the dried materials should be cooled in a desiccator. Record the weights as weights B.

Results:—Subtract the values B from the values A to find the weight of water lost and compute the loss to per cent of each of the materials.

EXPERIMENT 54

Object:—To compare the amounts and kinds of ash-forming substances in different plant tissues.

Apparatus and Materials:—Two small porcelain dishes, a stirring rod and brush.

Procedure:—In one dish burn the dried fodder or silage of Experiment 53 to a gray ash, adding small portions at a time. In the other dish burn an equal weight of the dry corn. Press the material upon the hot dish with the stirring rod, so as to burn all particles of carbon. The dish should not be heated more than to a dull redness at the bottom, as otherwise some ash material may be volatilized.

Results:—Which material contains the more ash?

Try the solubility of the ash in 5 c.c. of strong HCl and about 25 c.c. hot water. Rub the insoluble residue with the glass rod. Does it feel gritty? This is silica which forms a large part of the ash of grass stems.

EXPERIMENT 55

Object:—To show the formation of sugar in germinating seeds.

Apparatus and Materials:—Clean sand or sawdust, a small box, barley seed, mortar and pestle, filtering apparatus, Fehling's solution or silver nitrate solution, and test tubes.

Procedure:—Select 100 plump barley seeds and divide into two equal lots. Soak one lot in water for two hours and plant in moist sand or sawdust. Set in a dark place, keep moist and protect from mice. When the plumules are about an inch tall remove the seedlings and wash away sand and sawdust. Crush with 50 c.c. of water and a little sand in a mortar and filter the extract. Crush the ungerminated seeds in the same way. Now add 5 c.c. of each extract to separate 5 c.c. portions of Fehling's solution and boil.

Results:—A brick-red precipitate is cuprous oxide, formed by the reducing action of maltose. If silver nitrate solution treated with a few drops of NH_4OH is used in place of Fehling's solution, a gray, or shiny deposit of silver will be formed. Which material contains the more sugar? Save the extract of germinated barley. To preserve it for a time place in a bottle with a few drops of chloroform.

EXPERIMENT 56

Object:—To show that maltose is formed from starch by the action of an enzyme in germinating seeds.

Apparatus and Materials:—The extract of germinated barley prepared in Experiment 55, corn starch, water bath, and test tubes.

Procedure:—Boil about ½ gram starch with 50 c.c. of water for several minutes Cool and place about 5 c.c. of this starch paste in each of two test tubes. To one tube add 10 c.c. of the extract of germinated barley. To the other tube add 10 c.c. of the same extract which should be first boiled and cooled. Mark the two tubes so that they can be distinguished from each other. Immerse them for an hour in water kept at 40°C., stirring occasionally.

Results:—Now boil to drive off the chloroform and test each solution for sugar as in Experiment 55. An enzyme called diastase is active in germinating seeds which contain starch. Its power is destroyed by heat.

EXPERIMENT 57

Object:—To show the presence of fat in seeds.

Apparatus and Materials:—A small, wide mouthed bottle with stopper, a mortar and pestle, filtering apparatus, gasoline, flax seed, sunflower seed or soy bean.

Procedure:—Put out all flames on the laboratory desk. Crush a small handful of flax seed in a mortar. Place it in the bottle and add

50 c.c. of gasoline. Stopper and shake occasionally for about an hour. Filter, taking great care to avoid working near flames with the inflammable gasoline.

Results:—Pour a few drops of the extract on a dry filter paper. What kind of spot is left on it? Set the rest of the extract aside to evaporate. How does the residue feel? Heat it till fumes appear, and notice the odor. Is it a familar one?

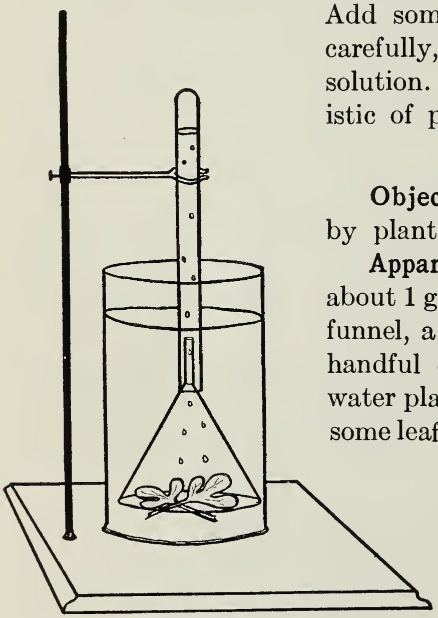
EXPERIMENT 58

Object:—To show the presence of proteins in seeds.

Apparatus and Materials:—Solution of common salt of 5% strength, kidney beans, hemp seed or cotton seed meal and gasoline.

Procedure:—Crush a handful of the seed and extract it with gasoline. Pour off the extract and spread out the residue of the seed till the gasoline has evaporated. Shake up the residue with salt solution and let it stand for a day with occasional stirring. Filter the extract and pour it into 2 or 3 liters of water.

Results:—The sticky mass which separates is a globulin. The globulins are by far the most abundant plant proteins. A particular one known as phaseolin forms $\frac{1}{5}$ of the kidney bean. Get some of your preparation by filtering or pouring off the diluted salt solution. Add some strong nitric acid to it and follow, carefully, by an excess of NH_4OH or NaOH solution. The color changes are characteristic of proteins.



EXPERIMENT 59

Object:—To show that oxygen is set free by plants in the process of photo-synthesis.

Apparatus and Materials:—A glass jar of about 1 gallon capacity, a wide short-stemmed funnel, a test tube, a support and clamp, a handful of elodea or some other vigorous water plant. (If no water plants are available some leafy twigs of any rapidly growing shrub may be used.)

Procedure:—Place the plant fragments in the jar and cover them with the inverted funnel. The latter should not reach to the top of the jar. See Figure. It should also be set on pieces of glass tubing to raise it ½ inch or so from the bottom of the jar. This is to permit diffusion of air to the leaves readily. Add water to a depth of about ½ inch over the tip of the funnel. Fill the test tube with water and invert it over the stem of the funnel.

Results:—Place the apparatus in a well lighted place and observe the bubbles which form. Do they form when the apparatus is darkened?

When the water has been displaced from the test tube, remove it, covering with the thumb. Turn the tube upright and thrust a glowing splinter into it. What gas is present?

EXPERIMENT 60

Object:—To show that plants excrete carbon dioxide as a product of respiration.

Apparatus and Materials:—Two one quart Mason jars with covers and new rubbers, a vigorous plant of coleus or some other rapidly growingform, saturated limewater, a small bottle, two flat dishes of 25 or 30 c.c. capacity.

Procedure:—Pour 25 c.c. of limewater into each flat dish. Place one of the dishes in each Mason jar. Place the plant cutting in one jar with its cut end resting in the small bottle filled with water. Seal the jars tightly and place them in a dark, moderately warm place.

Results:—Examine the limewater on the following day. In which bottle is the more precipitate present? Add a little HCl to it. What is it and how was it formed?

EXPERIMENT 61

Object:—To show that certain inorganic elements are essential to growth.

Apparatus and Materials:—Three one-pint Mason jars and thin corks to fit them, barley or wheat seedlings obtained as in Experiment 55, but grown in the light, 500 c.c. of 0.5% solutions of KNO_3 and NaCl, and cotton batting.

Procedure:—Number the jars 1, 2 and 3. Fill 1 with water, 2 with KNO_3 solution and 3 with the NaCl. Cut eight small wedges from the circumference of the cork with a thin sharp knife, saving the wedges. Wrap the seedlings with a little cotton at the base of the stem and fix one in each cut of the corks. Cut off the tips of the wedges and replace them, fixing them in place by an elastic band or string around the circumference of the cork. Leave the jars in a warm light place for two or three weeks, putting fresh liquid into each jar every two or three days. Do not use a room where gas is delivered.

Results:—What differences do you observe? The reserve food in the seeds will keep the plants growing in distilled water some time. Which salt supplies the more essential elements to the plant? A mixture of salts which will produce mature plants in water culture can be provided.

CHAPTER VII.

EXPERIMENT 62

Object:—To show some of the properties of silicon compounds related to soil minerals.

Apparatus and Materials:—Pure, fine sand, Na_2CO_3, strong solutions of $CaCl_2$ and of alum, HCl and iron crucible or deep dish.

Procedure:—See if three or four grains of sand will dissolve in hot conc. HCl. Mix about a gram of the sand with 20 times its weight of solid sodium carbonate and fuse to a liquid condition in an iron crucible. Continue heating for 10 or 15 minutes. Cool and extract the mass with 100 c.c. of boiling water. Filter. The solution contains sodium silicate and when very strong, is known as water glass. To 10 c.c. of the filtrate in a test tube add HCl gradually. The gelatinous precipitate is silicic acid. Filter and wash.

Results:—Add a bit of the precipitate, of pinhead size, to 4 or 5 c.c. of hot, strong Na_2CO_3 solution. Is it soluble? What is formed? Dry some of the precipitate in the oven and heat it a moment in the flame. Is it now readily soluble in strong Na_2CO_3 solution? Why?

To 5 c.c. of the waterglass solution add a little strong $CaCl_2$ solution. To another portion add alum solution. The insoluble calcium and aluminium silicates are abundant among soil minerals.

EXPERIMENT 63

Object:—To show that some soil minerals change soluble phosphates of fertilizers to insoluble compounds.

Apparatus and Materials:—Strong solutions of ferric chloride, calcium chloride and di-sodium phosphate.

Procedure:—Add about 5 c.c. of the phosphate solution to the same volume of ferric chloride solution. Notice the color of the precipitate. It is ferric phosphate. Repeat, using calcium chloride in place of ferric chloride.

Results:—What happens when mono-calcium phosphate of acid-phosphate fertilizer comes in contact with either limonite or calcite in the soil?

EXPERIMENT 64

Object:—To test for organic matter in soils rich in humus.

Apparatus and Materials:—Two porcelain crucibles or dishes with covers, samples of a sandy soil and rich garden soil or peat.

Procedure:—Place a small amount of each soil in separate dishes, cover and heat gradually over the flame.

Results:—What change of color do you observe? Is it equally intense in the two soils? This charring test is due to the separation of carbon from organic matter. It does not occur appreciably when air is freely admitted as by burning in an open dish. Why?

EXPERIMENT 65

Object:—To show acid properties of humus.

Apparatus and Materials:—A tall, small cylinder or wide mouthed bottle, strongest HCl diluted 40 times. Strongest ammonium hydroxide diluted 7 times and rich garden soil or peat.

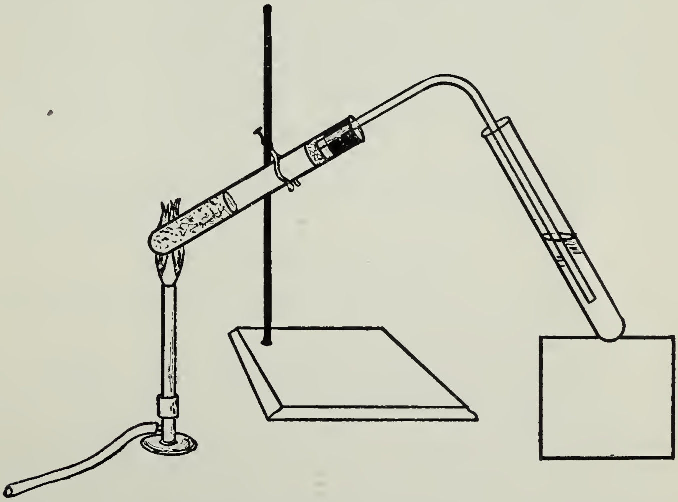
Procedure:—Stir a small handful of the air-dry soil with 400 c.c. of dilute HCl for three or four minutes, let settle about 15 minutes, and pour off or filter away the acid. Repeat once with acid and twice with water. Add 400 c.c. of the dilute ammonium hydroxide solution, stir occasionally for about an hour, and let settle over night.

Results:—Draw off some of the solution with a pipette. What is its color? It contains humus combined with ammonia. Add strong HCl gradually. Does a precipitate form? The insoluble humus is displaced from its union with ammonia.

EXPERIMENT 66

Object:—To show the presence of nitrogen in humus.

Apparatus and Materials:— A test tube with cork and delivery tube so bent as to dip into a second test tube partly filled with water. Rich garden soil or peat recently dried in the oven, and solid NaOH.



Procedure:—Mix 10 grams of soil with an equal bulk of powdered NaOH. Place in one test tube inclined upward and arrange the delivery tube to dip nearly to the bottom of the second test tube. See Figure. A loose wad of cotton—asbestos wool is better—

should be placed just beneath the stopper of the tube containing soil. Now test the water in the second tube with red litmus paper. It should not be alkaline. Gradually heat the soil. At first air will expand and bubble through the water in the second tube. Water collects in the cotton. It comes from the oxidation of organic matter in the soil. Continue heating the soil for several minutes. Remove the receiving tube and then remove the flame.

Results:—Test the water again with red litmus paper. Is it alkaline? The change is due to the formation of ammonia from organic compounds of the humus.

EXPERIMENT 67

Object:—To compare the power of different soil constituents to absorb water.

Apparatus and Materials:—Fine sand, clay and peat which have been air-dried by spreading in a thin layer on the laboratory bench for two or three weeks. Three tomato cans of uniform size and with bottoms perforated by small holes, and a rough balance.

Procedure:—Fit a filter paper into each can over the perforated bottom. Number the cans 1, 2 and 3. Fill 1 with sand, 2 with clay and 3 with peat, rapping each sharply down once upon the bench when one third, two thirds and wholly filled. Level off the soils and weigh the cans and contents. Support the cans upright on the edges of brick placed parallel in the sink. Run water upon each until it drains away freely from the bottom. Cover and leave over night.

Results:—Dry the bottoms with a cloth and weigh. The gain of weight in grams is equal to the c.c. of water retained by equal volumes of the soils.

What is the absorbing power of the other soils as compared with sand.

EXPERIMENT 68

Object:—To show the effect of a soil mulch upon the loss of water from soil by evaporation.

Apparatus and Materials:—Loam soil, two shallow one-quart tin dishes, and a large balance.

Procedure:—Mix the soil. Fill each pan with it to a depth of about three inches. Add the soil in layers of about 1 inch depth, moistening each layer with water until just sticky. The water added should be measured and made equal in the two pans. Thoroughly till the surface inch of soil in one pan with a thin knife or spatula. Weigh the pans and record weights as weights A. Let them stand in the laboratory for a day and weigh again, recording as weights B.

Results:—Subtract B from A and determine whether the tilled soil or mulch has reduced the loss of water by evaporation.

EXPERIMENT 69

Object:—To show that lime flocculates clay.

Apparatus and Materials:—Clay soil, pulverized quick lime, mortar and pestle, two 100 c.c. cylinders or similar tall jars, and a 500 c.c. beaker or bottle.

Procedure:—Fasten a rubber cap over the pestle. Place a small handful of soil in the mortar and rub it gently under the pestle with 50 to 100 c.c. of water. Repeat 3 times, pouring off the liquid each time into the beaker. Stir the contents of the beaker and let settle for 5 minutes. Without disturbing the sediment pour about 100 c.c. of the suspended clay into each of the cylinders. Add ½ gram of lime to one jar and shake both jars thoroughly for two or three minutes.

Results:—Let the cylinders stand and observe them occasionally for a day or so. What effect does the lime have?

EXPERIMENT 70

Object:—To show that excess of water makes the soil cold.

Apparatus and Materials:—Air dried muck or peat, two cigar boxes or quart dishes, two thermometers (one thermometer can be used) whose difference of reading at room temperature is known.

Procedure:—Sift the soil as fine as can readily be done. Fill each box with it compactly. Leave box 1 dry but add to box 2 all the water the soil will absorb. Place in a sunny spot and bury the bulb of a thermometer just below the surface of the soil in each box.

Results:—After ½ to 1 hour read the temperature and correct for any difference in the thermometers.

The evaporation of water and its own latent heat keep the soil cold. What is the remedy?

CHAPTER VIII.

EXPERIMENT 71

Object:—To study some characteristics of common fertilizer ingredients.

Apparatus and Material:—Test tubes, funnel, and filter papers. Sodium nitrate, ammonium sulphate, calcium cyanamide, dried blood, tankage, floats, steamed bone meal, acid phosphate, sulphate of potash, and nitrate of potash.

Method:—Examine each of the materials separately as follows. State their color, form, and general appearance. Allow a portion of each to be exposed to the air over night, or longer, if necessary. Test the solubility of each in water as follows. Place 2 grams in a test tube, add 15 c.c. water and heat, if necessary, to dissolve the solid. Filter off the clear liquid and evaporate to dryness.

Results:—What substances are affected by the atmosphere? What constituent of the air is responsible for this? Is there any evidence of solubility of these fertilizer materials in water? Which samples dissolve most readily? Which samples are comparatively insoluble in water? Of what significance is the solubility of fertilizers in actual farm practice?

EXPERIMENT 72

Object:—To study the solubility of commercial fertilizers or mixtures.

Apparatus and Material:—Watch glass, funnel, filter papers, water oven, balance and weights, some commercial fertilizers.

Method:—Dry and weigh a 9 cm. or 11 cm. filter paper. Fit in a funnel and place in it 2 grams of some commercial fertilizer. Pass through the filter between 250 and 500 c.c. distilled water, a little at a time, at about ordinary temperature. Transfer the filter paper and its contents to a watch glass, dry in a water oven, and weigh. Examine the insoluble residue and note whether it is composed of bone, blood, animal refuse, sand, or other material. Compute the percentage of material that was dissolved by the water. Repeat the experiment, using a different fertilizer. Or, several students, who are studying different samples, can compare notes.

Results:—What conclusion can be drawn concerning the immediate availability of the fertilizer? From the character of the residue, if any, what conclusion can be drawn in regard to the value of the fertilizer for the purpose for which it is intended?

EXPERIMENT 73

Object:—To study the availability of nitrogenous fertilizers.

Apparatus and Material:—Beakers, funnels, and filter papers, pepsin solution, dried blood, tankage, steamed bone meal.

Method:—Prepare a pepsin solution by dissolving 5 grams of commercial pepsin in a liter of water and add 1 c.c. strong hydrochloric acid. Place exactly ½ gram of dried blood, tankage, and steamed bone meal in separate beakers. To each of these add 200 c.c. pepsin solution and place the beakers in a warm position where the temperature is about that of the body (40°C.). Stir occasionally and, at the end of 5 hours or over night, filter off the insoluble matter remaining in the beakers, dry and weigh.

Results:—Note the color of the solution and the character of the residue. Compute the percentage of soluble matter. Which of these fertilizers do you conclude is the most available, considering the evidence at hand?

EXPERIMENT 74

Object:—To study the availability of phosphate fertilizers.

Apparatus and Material:—Test tubes, funnel, and filter papers, bone ash, acid phosphate, floats, nitric acid, ammonium molybdate.

Method:—Test the solubility of bone ash, acid phosphate, and floats in water and in nitric acid as follows. To about one gram of bone ash in a test tube add 20 c.c. distilled water, heat for a few minutes, and filter. Warm the filtrate till hot to the touch (about 50°C.) and add 5 c.c. ammonium molybdate. Place the test tube in the rack allow to stand while proceeding with the rest of the experiment. In another test tube treat one gram of bone ash with 15 c.c. water and 5 c.c. nitric acid. Shake the mixture for two minutes and filter. Warm the filtrate and add ammonium molybdate as before. Repeat these tests with the other two materials.

Results:—State in which of these tests it was possible to secure a result. What do these results mean? Compare the behavior of these substances and indicate which is the most available. Which is the least available? Which of these phosphate fertilizers should be bought, if immediate returns are wanted? Which is the cheapest material to buy for the permanent upbuilding of the soil phosphorus?

EXPERIMENT 75

Object:—To test for nitrates in fertilizers.

Apparatus and Material:—Test tubes, funnel, filter papers, 5 c.c. pipette (or glass tube), sodium nitrate, ferrous sulphate crystals, sulphuric acid, and several commercial fertilizers.

Method:—Dissolve a small piece of sodium nitrate in about 15 c.c. water. Add to this solution a few small crystals of ferrous sulphate and shake the tube until the crystals pass into solution. Draw up 5 c.c. strong sulphuric acid in a pipette, lower the latter to the bottom of the solution which has just been prepared, and carefully allow the acid to flow into the solution. Remove the pipette and allow the mixture to stand for a few minutes.

Part B. Stir 2 or 3 grams of the fertilizer to be tested with about 20 c.c. water for a few minutes and filter. Divide the filtrate into two equal portions in test tubes. To one of these add a few small crystals of the ferrous sulphate and shake until dissolved. To both portions of the solution add 5 c.c. strong sulphuric acid as before.

Results:—Does a brown coloration appear at the zone of contact between the acid and the sodium nitrate solution? This is due to a compound formed by the reaction between the ferrous sulphate and nitric acid. How is the nitric acid formed? Does any similar result occur in the case of the water solution of the fertilizer? It is necessary to carefully distinguish between this positive test and any charring in the control tube, that receiving no ferrous sulphate. Such charring may occur if the fertilizer contains soluble organic matter.

EXPERIMENT 76

Object:—To test for ammonia in fertilizers.

Apparatus and Material:—Test tubes, strong sodium hydroxide, ammonium sulphate, red litmus paper, and commercial fertilizers.

Method:—Prepare a dilute solution of ammonium sulphate. To 5 c.c. of this solution add 5 c.c. of the strong sodium hydroxide. Heat gently and cautiously smell the vapors. Suspend a moist red litmus paper in the vapors. Prepare a water solution of a fertilizer as in the previous experiment. Test this with the sodium hydroxide as described for the ammonium sulphate.

Results:—State the result of these tests upon the litmus paper and upon the sense of smell. What do you conclude in regard to the presence of ammonia in combination in the fertilizer?

EXPERIMENT 77

Object:—To test for organic forms of nitrogen in fertilizers.

Apparatus and Material:—Bunsen burner, untanned leather, wood shavings, tallow, wool, blood, and commercial fertilizers.

Method:—Burn small pieces of untanned leather, wood shavings, and tallow separately. Observe the difference in odor of the smoke. Test wool and blood in the same way. Also apply the test to various fertilizers, which may contain blood, tankage, or other protein carrier of nitrogen, comparing the odor with that produced by burning wool or leather at the same time.

Results:—Is there any difference in the character of the odor from the burning of these different materials? When have you observed an odor like that of burning wool? It is characteristic of protein materials. What do you conclude regarding the presence of organic nitrogen in the fertilizers tested?

EXPERIMENT 78

Object:—To test for potassium in fertilizers.

Apparatus and Material:—Test tubes, funnel, and filter papers, a saturated solution of tartaric acid, potassium chloride, ammonium hydroxide, ammonium oxalate, and commercial fertilizers.

Method:—Prepare a saturated solution of tartaric acid. Add 5 c.c. of this to an equal volume of a solution of potassium chloride. Place the test tube containing the mixture to one side and proceed with the experiment. Treat 2 or 3 grams of fertilizer with 10 c.c. water and filter. To about 5 c.c. of the solution add an equal volume of the saturated tartaric acid solution. If the fertilizers contain acid phosphate, it will be necessary to remove the calcium from the solution before adding the tartaric acid. Do this by means of a slight excess of ammonium hydroxide and ammonium oxalate solution, and filter. Test the filtrate.

Results:—Does a precipitate form when the solutions of tartaric acid and potassium chloride are mixed? This is not potassium tartrate but potassium hydrogen tartrate, or acid tartrate. Do you obtain a similar result in testing the solution of the fertilizer?

EXPERIMENT 79

Object:—To prepare acid phosphate.

Apparatus and Material:—Test tubes, funnel, and filter papers. bone ash, rock phosphate, strong sulphuric acid, and ammonium molybdate.

Method:—Thoroughly mix 10 grams of bone ash or rock phosphate with 6 grams of strongest sulphuric acid. Spread the mass on a piece of waste board to harden. After 24 hours pulverize the mass in a mortar and prepare a solution of the material by treating with 20 c.c. water. Make a similar solution from 10 grams of the original material. To 10 c.c. of each solution add 5 c.c. ammonium molybdate and heat to about 50°C. as in previous experiments. Let stand a few minutes.

Results:—Compare the amount of precipitate obtained from the acid phosphate which you prepared with that from the original phosphate material. What effect does sulphuric acid have upon the solubility of bone ash or rock phosphate?

EXPERIMENT 80

Object:—To compare the effects produced on plant growth by the different essential elements of fertilizers.

Apparatus and Material:—Four boxes or jars which will hold 10 pounds of soil, barley or oat seeds, sodium nitrate, potassium chloride, and sodium hydrogen phosphate.

Method:—Secure some unmanured loam soil, mix well, and weigh out four 10 pound portions. Plant six plump barley or oat seeds in each lot of soil. Number the boxes or jars 1, 2, 3, and 4. Water them moderately with the same volume of water and cover until the seedlings break through the soil. Now add the fertilizer elements in the water applied as follows: 6.1 grams sodium nitrate to box 1; 4.47 grams disodium phosphate to box 2, and 1.9 grams potassium chloride to box 3. Leave box 4 untreated as a control. Continue the watering as required and in three or four weeks repeat the application of the fertilizers. The total amounts of each of these fertilizer elements will now have been 1 gram each. Continue the experiment to maturity if practicable.

Results:—Make notes on the difference in growth of the plants in the different jars as they approach maturity. What seems to be the chief effect of each of the three essential elements applied? What relations have these effects to the soil under examination?

CHAPTER IX.

EXPERIMENT 81

Object:—To show difference in stability of ammonium salts.

Apparatus and Materials:—Test tubes, ammonium sulphate, and ammonium carbonate.

Procedure:—Heat about ½ gram of ammonium sulphate in a test tube. Notice the fumes and their odor. A sublimate of ammonium bisulphate appears on the upper cool walls of the tube. Test the fumes with the moistened litmus paper.

Repeat the test with ammonium carbonate. What forms on the walls of the test tube? What are the other products of decomposition? This salt gives the familiar stifling odor to heating horse manure.

Results:—Which salt is the more stable toward heat? Gypsum is sometimes spread over the manure to prevent loss of ammonia. What more stable salt does it form from the ammonium carbonate?

EXPEQIMENT 82

Object:—To show formation of ammonia from urea of urine.

Apparatus and Materials:—Human urine, (this is used because, like the urine of carnivorous animals, it is much richer in urea than that of the herbivorous farm animals), litmus paper, test tubes, and wood ashes.

Procedure:—Boil 5 c.c. of the fresh urine in a test tube, and, as it approaches dryness, test the escaping vapors with moist red litmus paper.

Place a handful of fine wood ashes on a filter and wash them with water until about 50 c.c. of leaching have collected. Return the leachings through the ashes twice. Add 5 c.c. of the leachings to 5 c. c. of the urine and boil. Test the vapors with red litmus paper.

Results:—Urea gives off part of its nitrogen as ammonia, when gently heated. When heated with alkali, such as the K_2CO_3 of wood ashes, it combines with water and decomposes to ammonia and carbon dioxide. This latter change is caused also by bacteria in the manure. Is it desirable? Is it good practice to add ashes to manure in piles? Is it safe to add quick lime?

EXPERIMENT 83

Object:—To compare the efficiency of different litters in absorbing urine or the liquid manure.

Apparatus and Materials:—Wheat straw or some similar small straw, shears, a pail of water and a large shoe box.

Procedure:—Weigh two equal quantities of the straw of 1 foot lengths which nearly fill the box when pressed down. Cut one lot of the straw into pieces about 1 inch in length. Soak the lot of long straw thoroughly in water, drain and shake off the surface water and weigh. Do the same with the cut straw.

Results:—Which lot of straw has the greater absorbing power? Does it pay to cut the litter used for bedding?

Peat has much greater efficiency than straw as an absorbent. As it decays hardly at all, however, it should not be used in great quantity with manure to be piled. If so used it will increase the loss from fermentation.

EXPERIMENT 84

Object:—To compare the amounts of water in a fermentable or "hot" manure and a non-fermentable or "cold" manure.

Apparatus and Materials:—Fresh horse manure and cow manure, each quite free from litter, and two one-pint tin dishes.

Procedure:—Weigh the dishes, numbering them 1 and 2. Fill number 1 with horse manure packed down and number 2 with cow manure. Weigh again. Now dry in the oven for a day or more and cool. (Cool preferably in a large desiccator.) Weigh.

Results:—Divide the losses of weight by drying by the weights of the respective fresh manures. Which manure is the drier? Which ferments the more readily?

EXPERIMENT 85

Object:—To show the relation of water and air to the loss of nitrogen by fermentation in hot manure.

Apparatus and Materials:—Fresh horse manure free from litter, two deep boxes of about ½ bushel capacity, and two thermometers whose difference in reading, if any, is known.

Procedure:—Fill one box with manure, packing lightly. Fill the other box in layers, wetting and firmly packing each layer until the box is full. Bury the bulb of a thermometer near the center of each box. Place in warm room.

Results:—At intervals of a day read the temperatures of the manures. Correct for differences of reading of the thermometers. Which manure has heated the most?

Watering and packing deprive some of the bacteria of their necessary air. The water also absorbs heat and retards chemical changes.

EXPERIMENT 86

Object:—To show the power of soil to absorb ammonia escaping from manure.

Apparatus and Materials:—Two stoppered bottles or jars of 1 pint capacity, moist clay loam, garden soil or peat, and powdered ammonium carbonate.

Procedure:—Cover the bottom of each jar with a thin layer of ammonium carbonate. To one jar add a covering of the moist soil about 1 inch deep. Stopper the jars and leave on the laboratory bench.

Results:—After an hour or more test the odor in each jar. In which case has the more ammonia become free?

EXPERIMENT 87

Object:—To compare the fertilizing value of leached with unleached manure.

Apparatus and Materials:—Two strong boxes of nearly equal size which hold 50 pounds of loam or sandy soil each, fresh cow manure with urine well saved by bedding, cheese cloth, tin pan and well mixed sandy soil or loam.

Procedure:—Weigh out two fifty-pound lots of soil or measure out two half-bushel lots of it. Weigh out two one-pound lots of the manure. Mix one lot of the manure into one lot of soil, place the mixture, with settling, into one box and label it "Unleached manure." Stir the other lot of manure with enough water to make it liquid and squeeze out the water through two or three layers of cheesecloth. (The solution will not filter readily.) Repeat the washing with water twice. Mix the residue of the manure with the second lot of soil. Fill the second box and label it "Leached Manure." Plant a few kernels of corn in each box, place in a warm sunny spot and keep well watered.

Results:—Which kind of manure produces the better growth? Why?

CHAPTER X.

EXPERIMENT 88

Object:—To test for the chief chemical constituents of bones.

Apparatus and Materials:—Green bones. If a bone cutter can be had, they should be chopped to small pieces. A large iron dish or crucible, a mortar and pestle, dilute HNO_3, strong acetic acid, solution of ammonium molybdate, and solution of ammonium oxalate.

Procedure:—Weigh out 100 grams of bone. Burn it thoroughly and weigh the ash. What is the per cent of ash in the bone?

Pulverize a little of the bone ash in the mortar. Add about ½ gram to 10 c.c. of water in a test tube and add acetic acid until it is mostly dissolved. To the clear solution add a few drops of ammonium oxalate solution. The precipitate is calcium oxalate.

Dissolve another ½ gram portion of the ash in 10 c.c. of dilute nitric acid. Heat to boiling and add 5 c.c. of ammonium molybdate solution with stirring. The yellow compound is an ammonium salt of phosphoric and molybdic acids.

Results:—What is the chief inorganic compound of bones?

EXPERIMENT 89

Object:—To show the presence of sulphur in keratin.

Apparatus and Materials:—Hair cuttings or shavings of horn or hoof, lead acetate solution, concentrated sodium or potassium hydroxide solution and concentrated HCl.

Procedure:—Place about ½ gram of fine material from hair, horn or hoof in a test tube. Boil several minutes with 5 c.c. of strong sodium or potassium hydroxide solution, adding water to replace any appreciable loss by evaporation. Cool, dilute with about an equal volume of water, and make acid with HCl. Transfer to a small necked flask. Moisten a filter paper with lead acetate solution and hold it over the neck of the flask while boiling the acidified solution.

Results:—The blackening of the paper is due to the formation of lead sulphide. It is caused by hydrogen sulphide set free from potassium sulphide by the HCl. What was the source of the sulphur in H_2S?

EXPERIMENT 90

Object. To show the relation in composition of muscular tissue and excretory products of the kidneys to food proteins.

Apparatus and Materials:—Fresh lean meat, fresh human urine, dilute copper sulphate solution, strong NaOH solution and conc. HNO_3.

Procedure:—Review Experiment 58 of Chapter 6. Add strong HNO_3 and excess of NaOH solution successively to a bit of muscle tissue, heating. What is its composition?

Boil a bit of the tissue with strong NaOH solution. Cool and add two or three drops of $CuSO_4$ solution down the side of the test tube. What color appears in the upper part of the liquid? This is the biuret test for proteins.

Evaporate a few c. c. of urine in a dish and heat very gently till white solid material appears. Take up in a little water, transfer to a test tube and add successively a little NaOH solution and dilute $CuSO_4$ solution. What color appears?

Results:—Gentle heat drives ammonia from urea and forms biuret? What do you judge to be the food source of urea and related nitrogen compounds of the urine?

EXPERIMENT 91

Object:—To test for the most abundant inorganic constituent of urine.

Apparatus and Materials:—Fresh urine, NaOH solution, HNO_3 and dilute solution of silver nitrate.

Procedure:—Make 5 c.c. of the clear urine alkaline with NaOH, then acid with HNO_3. Add two or three drops of $AgNO_3$ solution.

Results:—The precipitate is silver chloride. What common salt do you judge to be abundant in urine?

In human urine urea forms about ½ and sodium chloride about ¼ of the total solids.

EXPERIMENT 92

Object:—To show the digestive action of saliva upon starch.

Apparatus and Materials:—Corn starch or any other common starch, a small lump of clean, soft paraffin, a beaker, a water bath (for which any small tin dish with perforated cover will serve), and filtering apparatus.

Procedure:—Chew a lump of paraffin and collect 2 or 3 c.c. of filtered saliva. Boil ½ gram starch with 50 c.c. of water for two or three minutes and cool. To 10 c.c. of the starch paste add 10 drops of saliva and number the test tube 1. To another 10 c.c. of paste add 10 drops of saliva heated to boiling and number the test tube 2. Mix the contents of the tubes and immerse them in the water bath through a hole or holes in the cover. Keep the bath at 40°C. and leave the tubes immersed 15 to 20 minutes. Now test the contents of each test tube for sugar by boiling 5 c.c. with 10 c.c. of Fehling solution.

Results:—The enzyme diastase of the saliva converts starch to maltose. Why was no maltose present in tube 2?

EXPERIMENT 93

Object:—To show the digestive action of pepsin in the gastric juice upon proteins.

Apparatus and Materials:—A fresh pig's stomach, a hard boiled egg, HCl and chloroform.

Procedure:—Wash the stomach and rip off the mucous lining with the aid of a sharp knife. (It requires two persons to do this readily.) Mince the lining in a meat chopper and suspend it in 500 c.c. of water in a stoppered bottle. Add 2½ c.c. of strongest HCl and 5 or 10 c.c. of chloroform, mix thoroughly, stopper and let stand for a day or two. Cut the white of a hard boiled egg into small cubes with a sharp knife. Place 6 cubes in each of two test tubes labeled 1 and 2. Filter about 25 c.c. of the stomach or pepsin extract and place 10 c.c. in tube 1. Place 10 c.c. of boiled extract in tube 2. Mix the contents of the tubes and keep them at about 40°C. for a day, stoppered with wads of cotton batting.

Results:—Do you observe any difference in sharpness of the corners of cubes in the two tubes? Filter the contents and make the filtrates alkaline with NaOH. Warm and add dilute solution of copper sulphate. In which case is the biuret test strongest? Why does no digestion occur in tube 2?

EXPERIMENT 94

Object:—To show that carbon dioxide is excreted from the lungs.

Apparatus and Materials:—Saturated lime water freshly filtered into a cylinder or tall bottle and a small pipette or a glass tube drawn out at one end.

Procedure:—Blow the breath steadily for several minutes through the limewater by means of the pipette or tube. Does the liquid become turbid?

Let the precipitate settle and then pour or draw off nearly all the overlying liquid. Add a little dilute HCl. What happens?

Results:—What is the precipitate and how was it formed?

EXPERIMENT 95

Object:—To prepare gelatine from collagen.

Apparatus and Materials:—Ground green bones, and HCl.

Procedure:—Place a handful of the ground bone in a small covered dish and add just enough water to make the mass stir easily. Add 2 or 3 drops of HCl, cover the dish and boil for an hour. Stir occasionally and replace water lost by evaporation. Filter about 5 c.c. of the extract and let it cool.

Results:—Does the extract set? If not, repeat the boiling. Filter and test at ½ hour intervals. The setting of the cooled extract is due to the formation of gelatine. Horn and hoof treated in the same way produce glue.

EXPERIMENT 96

Object:—To show the action of tannin upon proteins in tanning.

Apparatus and Materials:—Fresh eggs and tannin powder.

Procedure:—Stir a little tannin into 50 c.c. of hot water, cool and filter. Stir about 5 c.c. of egg white into 200 c.c. of cold water. To 10 c.c. of the protein solution add 5 c.c. of tannin solution.

Results:—The tannin forms a precipitate with the soluble protein.

CHAPTER XI.

EXPERIMENT 97

Object:—To show the presence of supplies of calcium and phosphorus in certain feeding stuffs.

Apparatus and Materials:—Two small porcelain dishes, wheat bran, alfalfa or clover hay cut fine, nitric and acetic acids and ammonium hydroxide, solutions of ammonium molybdate and ammonium oxalate.

Procedure:—Burn about 10 grams of bran and of hay in separate dishes. Dissolve the ash in 5 c.c. of strong HNO_3 and 20 c.c. of hot water. Filter 5 or 10 c.c. of the solutions into separate test tubes so marked that they can be identified. To the ash solution of the bran add 5 c.c. of ammonium molybdate solution and heat until hot to the touch.

To the solution of hay ash add a slight excess of NH_4OH, testing with litmus paper. Add 2 or 3 c.c. of acetic acid and 5 c.c. of ammonium oxalate and stir.

Results:—The yellow precipitate is a phosphorus compound. The white precipitate is calcium oxalate. Why are calcium and phosphorus important in feeding stuffs?

EXPERIMENT 98

Object:—To show differences in the nature of the ether extract of feeding stuffs.

Apparatus and Materials:—Two small wide mouthed bottles with stoppers, ether, alcohol, two sets filtering apparatus, corn meal, and clover or timothy hay cut fine.

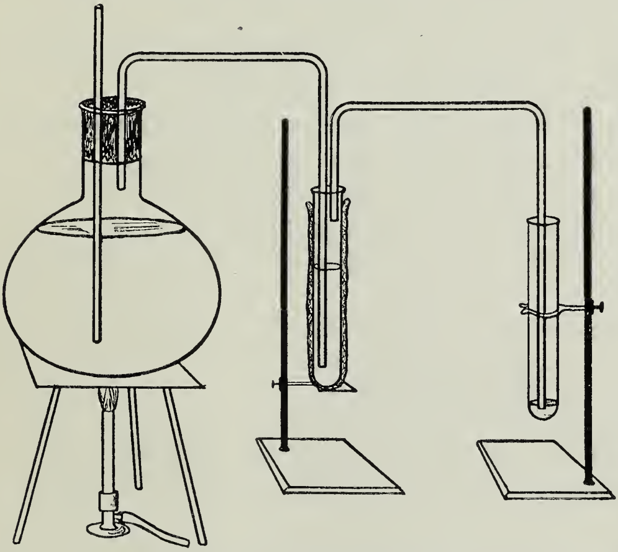
Procedure:—Dry the feeding stuffs in the oven. Place 10 grams of each in different dry bottles. Add 25 c.c. of ether to each bottle, cork and shake occasionally for about two hours. (Carefully avoid flames.) Filter into a wide dish and allow the ether to evaporate.

Results:—How does the residue feel? Add 10 or 15 c.c. of strong alcohol to each residue and stir. Does the alcohol take on a decided color in either case? This is due to chlorophyll. Which feeding stuff seems to contain the more true fat?

EXPERIMENT 99

Object:—To separate essential oils from feeding stuffs.

Apparatus and Materials:—A steam distillation apparatus as shown in the figure, fresh clover hay—sweet clover if possible—and fresh rape or turnips.



Procedure:—Place a little of the finely cut feeding material in the distillation test tube. Add a few c.c. of water and weakly acidify with sulphuric acid. Distill with steam into the receiving tube.

Results:—Observe the odor of the first few c.c. of distillate. The essential oil of hay is a compound called coumarin.

Repeat the test with rape or turnips. The volatile substances here are organic sulphur compounds.

EXPERIMENT 100

Object:—To compare the amount of crude fiber in huskless grains and in hays and straws.

Apparatus and Materials:—Cornmeal, finely ground corn stover or timothy hay or any common straw, two flasks of about 500 c.c. capacity fitted with one-holed stoppers, a glass tube about 1½ feet long to fit each stopper, filtering outfits, and filters of linen cloth.

Procedure:—Dry the feeding stuffs in the oven. Weigh 5 grams of each feeding stuff into separate flasks and shake it with gasoline in the usual way to remove fat. Filter off the gasoline and dry the residues. Return them to the flasks and add 200 c.c. of sulphuric acid of about 2 per cent strength (2 c.c. of strongest H_2SO_4 and 200 c.c. of water). Insert the corks and upright glass tubes to act as condensers and boil gently for ½ hour. Filter on cloth and wash with hot water. several times. Return the residue to the flasks and boil ½ hour with 2 per cent sodium hydroxide solution. Filter and wash as before.

Results:—Which feeding stuff contains the more crude fiber?

The dilute alkali dissolves the protein from the feeding stuffs. The dilute acid changes starch to glucose. The residue is chiefly cellulose.

EXPERIMENT 101

Object:—To prepare a typical collection of feeding stuffs with reference to supplies of both protein and energy.

Procedure:—Using a table of the composition of feeding stuffs select three or four which fall in each of the following classes:

1. High protein feeds—30 to 45% protein.
2. Medium protein feeds—20 to 30% protein.
3. Medium energy feeds—70 to 75% carbohydrates (nitrogen-free extract).
4. High energy feeds—75 to 85% carbohydrates.

CHAPTER XII.

EXPERIMENT 102

Object:—To compare the weight of whole milk and water.

Apparatus and Materials:—Large scales, ten-quart pail, and fresh whole milk.

Procedure:—Weigh 10 quarts of milk. Now weigh ten quarts of water at the same temperature. Divide the weight of milk by the weight of water.

Results: What is the value for the specific gravity of whole milk? The greater weight of the milk is due to the various compounds dissolved in it. What effect does skimming exert on the specific gravity of milk? What is the effect of watering?

EXPERIMNNT 103

Object:—To show that acid causes the curdling of milk.

Apparatus and Materials:—Sweet, skimmed milk, acetic acid of about 10% strength or a like strength of any of the common acids, and a large funnel arranged for filtering.

Procedure:—Add 400 c.c. of water to 100 c.c. of milk, having both at about room temperature. After mixing well add dilute acid slowly with constant stirring. After each small addition of acid watch for the separation of white casein particles from the liquid.

Then add a few drops more of the acid, stir vigorously, allow to settle, filter. Save the filtrate and wash the precipitate.

Results:—Treat the precipitate with strong HNO_3 followed by alkali. To what kind of compounds does casein belong?

EXPERIMENT 104

Object:—To show the presence of a sugar in milk.

Apparatus and Materials:—Filtrate from Experiment 103, Fehling's solution or $AgNO_3$ solution made alkaline by NH_4OH.

Procedure:—Make the filtrate neutral or faintly alkaline by NH_4OH. Evaporate to a volume of 10 to 20 c.c. Filter, if not clear, and boil it with 10 c.c. of Fehling's solution.

Results:—The reducing substance in milk is the di-saccharide sugar called lactose. What is its relation to souring?

EXPERIMENT 105

Object:—To test for some of the ash constituents of milk.

Apparatus and Materials:—Two hundred c.c. of skimmed milk, a small porcelain dish, solutions of ammonium oxalate, ammonium molybdate and silver nitrate, acetic and nitric acids.

Procedure:—Evaporate the milk in a porcelain dish and dry the residue in the oven. Burn to a grayish ash. Extract with a little nitric acid and about 25 c.c. of hot water, and filter. Divide the filtrate into three portions. To one portion add a few drops of silver nitrate solution; a white precipitate or turbidity shows that chlorine is present. To a second portion add 5 c.c. of molybdate solution and heat just hot to the touch; a yellow precipitate or turbidity denotes the presence of phosphorus. To the third portion add NH_4OH till slightly alkaline. A precipitate will form. Add acetic acid until the precipitate, which is calcium phosphate, dissolves. Add a little ammonium oxalate solution. A white precipitate or turbidity shows the presence of calcium.

Results:—Sodium chloride and phosphates of potassium and calcium are shown to be the most abundant salts in milk.

EXPERIMENT 106

Object:—To show the emulsified condition of fat in milk.

Apparatus and Materials:—A little fresh whole milk, a compound microscope, a mounting slide and cover glass and vaseline.

Procedure:—With vaseline draw a square smaller than the cover glass on the glass mounting slide. Place a drop of the mixed milk within it and press the cover slip firmly over it. The vaseline prevents evaporation from beneath the cover glass and keeps the fat globules quiet in the field of the microscope. Focus the microscope until you find the field dotted with spheres of various sizes. These are the fat globules suspended in the milk. Draw a small group of them.

EXPERIMENT 107

Object:—To show a difference between butter-fat and the fat of oleomargarine in behavior toward heat.

Apparatus and Materials:—Small samples of oleomargarine butter in good condition and test tubes.

Procedure:—Place a lump of "oleo" the size of a small walnut in a test tube and heat over the flame. Observe that the fat boils with much sputtering and little foam. Test some butter in the same way.

Results:—What difference from the "oleo" do you observe with butter? Notice the foam. This "foam test" distinguishes butter from oleomargarine.

EXPERIMENT 108

Object:—To show an important difference between the mixture of fats in butter and that in oleomargarine.

Apparatus and Materials:—Two small, long necked flasks, two funnels, strong solution of KOH, sulphuric acid, and two small, narrow bottles or beakers.

Procedure:—Melt a little "oleo" in one bottle and butter in another by setting them in the oven for a few minutes, with the door open. Decant 5 to 10 c.c. of clear "oleo" fat into one flask and of butter fat into the other. Add 20 or 30 c.c. of the KOH solution to each flask. Place the funnels in the necks of the flask, to serve as condensers. Boil gently for nearly ½ hour. Cool, dilute with an equal volume of water and make acid with sulphuric acid of about 50% strength.

Results:—Now heat the two solutions and observe the odor given off. Have you smelled it from butter before? It is due to acids of some of the fats in butter which are volatile when free. They become free in rancid butter. Buytric acid is important among them. Butter contains several fatty acids not present in oleomargarine.

EXPERIMENT 109

Object:—To show the volatile nature of some flavoring compounds of cheese.

Apparatus and Materials:—A little strongly flavored cheese and a steam distillation apparatus as used in Experiment 99, Chapter XI. or separating essential oils from feeding stuffs.

Procedure:—Mince a little cheese and pack it lightly around the steam delivery tube in the distilling flask or test tube. Distill with steam until 2 or 3 c.c. of distillate has collected in the receiving tube. Note the odor of the distillate. It is due to esters and other volatile compounds.

CHAPTER XIII.

EXPERIMENT 110

Object:—To show the production of dextrin from starch by the toasting of bread.

Apparatus and Materials:—Six medium thick slices of white bread, filtering apparatus and evaporating dishes.

Procedure:—Thoroughly toast three slices of the bread. Chop the remaining bread and the toast fine. Stir each in 500 or 600 c.c. of water for 10 minutes or so. Filter and evaporate the filtrates separately.

Results:—Which leaves the more residue? Is the residue sticky when it becomes thick? It consists chiefly of dextrin formed by heat from starch.

EXPERIMENT 111

Object:—To separate pectin from the turnip.

Apparatus and Materials:—Strong alcohol, cheese-cloth, grater, fresh turnip and HCl diluted 1:15.

Procedure:—Grate a turnip. Wash the pulp thoroughly with water, either on a large filter or by squeezing in two or three thicknesses of cheese-cloth. Place the pulp in about 100 c.c. of the dilute HCl for 2 days. Strain the extract through cheese-cloth and filter it. Pour the filtrate into an equal volume of strongest alcohol and let stand some time.

Results:—What sort of precipitate forms? It is pectin, derived from pectose in the turnip. Pectose causes the gummy character of quince fruit. It produces jellying when changed to pectin by boiling, but excessive boiling destroys it.

EXPERIMENT 112

Object:—To show the relations of sugars, acids and starch in ripening fruits.

Apparatus and Materials:—Solution of iodine and potassium iodide. Very green apples and ripe apples.

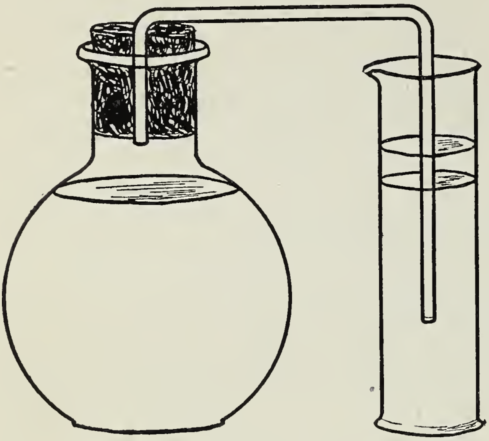
Procedure:—Cut some apples of each kind in halves across the cores. Dry the cut surfaces with filter paper. Paint them freely with the iodine solution.

Results:—Which lot of apples gives the stronger blue color of the test? Is any special figure formed by the color of the test on the cut surfaces?

EXPERIMENT 113

Object:—To test for the products of fermentation of sugar.

Apparatus and Materials:—Molasses, a 250 or 300 c.c. flask with one holed stopper, a glass tube fitting the stopper and bent to form a short and a long arm which are parallel. The short arm should not be more than two inches long, the other should about equal in length the height of the flask. A small cylinder or large test tube, kerosene, saturated limewater and yeast.



Procedure:—Add 50 c.c. of molasses to 250 c.c. of water and mix. Nearly fill the flask with the solution. Crumble ¼ of a fresh yeast cake into the flask. Fix the glass tube with its shorter arm just passing into the neck of the flask. Immerse the long arm in freshly filtered limewater in a cylinder. See the figure. Cover the limewater with a ¼ inch layer of kerosene. Leave the whole apparatus in a warm place (110 to 120°F.) for 3 or 4 days.

Results:—What change do you notice in the cylinder? Add a little strong HCl? What was the precipitate? How was it formed?

Place about 100 c.c. of the fermented fluid in the flask and distill about one third of it over into a clean receiving vessel. Replace this distillate alone in the flask and redistill about 5 c.c. Observe the odor of the last distillate. Boil it in a test tube and test the vapors at the mouth of the tube with a burning match. What is the other product of the fermentation besides alcohol?

EXPERIMENT 114

Object:—To show the chief chemical change of the fermentation of alcohol.

Apparatus and Materials:—A small open bottle and the residue of fermented sugar solution left in Experiment 113.

Procedure:—Place about 100 c.c. of the fermented solution in a clean open bottle. Let it stand several days in a warm place. Observe its odor. Distill ⅓ of it in the apparatus of Experiment 113 and test the distillate with blue litmus paper.

Results:—Acetic fermentation has taken place and alcohol has been oxidized to acetic acid. (Should the change not occur readily, add a little mother of vinegar to the solution. This will supply the lacking bacteria.)

EXPERIMENT 115

Object:—To prepare (synthesize) one of the esters which gives flavor and aroma to fruits.

Procedure:—To 5 c.c. of alcohol in a test tube add 5 c.c. of acetic acid and 1 c.c. of sulphuric acid. Heat gently with the mouth of the tube well away from the flame.

Results:—Notice the fragrant odor given off. It is due to the ethyl-acetate, a salt or ester formed from the alcohol and acetic acid. Amylacetate gives a pear odor. Ethyl butyrate gives a pineapple odor.

EXPERIMENT 116

Object:—To separate the proteins of wheat gluten.

Apparatus and Materials:—A small pan, strongest alcohol and one or two quarts of wheat flour.

Procedure:—Add water, a little at a time, while kneading the flour to a stiff dough. Wash out all white patches of starch by kneading the dough in gently running water. The product is gluten. Squeeze it as dry as possible. Mince it thoroughly in 9 parts of alcohol diluted with one part of water. Let stand for a day with occasional stirring. Filter and evaporate the filtrate saving the residue also.

Results:—The filtrate yields gliadin. The residue from the alcohol extraction is glutenin. Test each by strong HNO_3 followed by NH_4OH. To what class of compounds do they belong?

EXPERIMENT 117

Object:—To test for some of the food preservatives most commonly used.

Apparatus and Materials:—A little powdered borax, formalin solution of 40% strength, a small porcelain dish, alcohol, ferric chloride, about 300 c.c. of sweet unpasteurized milk, which may be skimmed milk, and saturated limewater.

Procedure:—Divide the milk into three nearly equal parts, labeled 1, 2 and 3. To part 2 add about ½ gram of borax and stir until dissolved. To part 3 add 10 drops of formalin and stir. Let stand in a warm room for a day or two. Is there now any difference in the condition of the three samples?

Evaporate 25 c.c. of sample 2 with 25 c.c. of saturated limewater, dry in the oven and burn to a gray ash. Add a few drops of strong sulphuric acid and a few c. c. of alcohol. Burn the alcohol, while stirring, against a white background. Watch for a green color on the edges of the flames.

Results:—The green flame is due to ethyl borate, an ester formed from boric acid freed from the borax. What freed the boric acid?

Pour 10 c.c. of sample 3 into a porcelain dish or thin teacup. Add 10 c.c. of strongest HCl and a very small pinch of ferric-chloride. Heat gradually while stirring with a rotary movement of the wrist. Watch for a violet color where the liquid forms a thin film on the sides of the dish. The violet color is a test for formaldehyde, the active agent of formalin.

It will be well to test for these preservatives in milks prepared by the teacher. To make your conclusions more reliable, always compare tests on your unknown sample with tests made at the same time on unpreserved milk.

CHAPTER XIV.

EXPERIMENT 118

Object:—To show some differences in the chemical properties of animal and vegetable fibers.

Apparatus and Materials:—Strongest nitric acid and ammonia, and threads of cotton, linen, wool and silk.

Procedure:—Burn some threads of wool and then of silk. Notice the odor produced. Burn cotton and linen. Do they burn at the same rate as wool and silk? Do they give the same odor as the wool and silk?

Immerse some threads of each kind in separate portions of strongest NH_4OH. Which fibers dissolve?

Dip the threads of the different fibers in strongest nitric acid and then in ammonia. Which show a protein test by turning yellow to orange?

EXPERIMENT 119

Object:—To show some principles of dyeing.

Apparatus and Materials:—A solution of tannin, made by stirring a few grams of tannin powder in about 200 c.c. of hot water for some time, a ferrous sulphate solution of 5 to 10 per cent strength, acetic acid of 5 to 10 per cent strength and cotton cloth.

Procedure:—Soak a piece of cotton cloth in tannic acid solution and dry it. Soak it in ferrous sulphate solution and dry again. Cut into two pieces. Immerse one piece in a little boiling water and the other in dilute acetic acid.

Results:—The black dye is ink. Is it "fast"? Why is the juice of lemon a good remover of ink stains?

EXPERIMENT 120

Object:—To show the chemical properties of some paint materials.

Apparatus and Materials:—Olive oil, linseed oil, turpentine, strong solution of NH_4OH, pitch and dry varnish.

Procedure:—Paint a smooth bit of board with a coat of olive oil. Paint another with linseed oil. Feel the surface after a day or two. Linseed oil "sets" because it takes up oxygen to satisfy some extra chemical bonds or affinities which it has.

Add bits of pitch and varnish to a little turpentine. Do they dissolve? Does the varnish dissolve in NH_4OH solution? Would you recommend turpentine or ammonia water for cleaning varnished surfaces?

EXPERIMENT 121

Object:—To compare the amounts of free alkali in different soaps.

Apparatus and Materials:—Filtering apparatus with fairly large funnels, a washing powder, a high grade toilet soap, dilute hydrochloric acid—1 part strongest acid diluted by 100 parts of water—phenolphthalein indicator, and a burette or dropping device.

Procedure:—Weigh 10 grams of washing powder into one filter. Shave the soap fine and weigh 10 grams into the other filter. Wash each with small portions of hot water until about 200 c.c. of washings have collected. Add a few drops of phenolphthalein to each soap solution and determine which requires the more of the weak HCl to destroy the color.

Results:—Disappearance of the pink color shows that the free alkali has been neutralized. Which is the more alkaline, the soap or the powder?

EXPERIMENT 122

Object:—To show the relation of heat to the preparation of plaster from gypsum.

Apparatus and Materials:—Two small porcelain or metal dishes, gypsum, and an oven which can be heated to 130°C.

Procedure:—Heat two small quantities of gypsum, in numbered dishes, to not over 130°C. Heat dish 2 very hot over a flame. Cool the two dishes. Stir the contents with a little water to form a paste.

Results:—Which portion "sets" to a hard mass? The product is plaster of Paris. The other portion is "dead-burned" and no longer "sets."

EXPERIMENT 123

Object:—To prepare and test Paris green. **(Handle with care!)**

Apparatus and Materials:—Arsenious oxide, commonly known as white arsenic, copper acetate, strong NH_4OH solution and filtering apparatus.

Procedure:—Add 0.5 gram of arsenious oxide to 25 c.c. of water and boil for 5 to 10 minutes. Filter from any insoluble material.

Dissolve 0.75 gram of copper acetate also in 25 c.c. of hot water. Pour the boiling hot solutions together into a third vessel.

Results:—The green precipitate which forms is a compound of copper with both arsenious and acetic acids. It is the true Paris green. Test its solubility in NH_4OH solution. (The antidote for arsenic poisoning is fresh, moist ferric-hydroxide.)

EXPERIMENT 124

Object:—To prepare lime-sulphur wash and test the action of air upon it.

Apparatus and Materials:—Flowers of sulphur, pulverized, fresh quick-lime (CaO), a dish of about one quart capacity, two flat bottomed dishes eight or ten inches in diameter, kerosene, HCl and solution of barium chloride.

Procedure:—Add 10 grams of lime to 300 c.c. of water and stir for a short time. Stir in 20 grams of sulphur. Heat gradually with occasional stirring. Finally boil for ½ hour or more, keeping the volume up by adding water and stirring frequently. When the wash is cool pour a shallow layer of it into each of two flat bottomed dishes. Cover the wash in one dish with a layer of kerosene ½ inch or more in depth. After several days examine the two dishes.

Results:—Is there any difference in appearance of the two samples? Pour off the wash from each dish separately, barely acidify with HCl and warm. Filter from residues and add a little $BaCl_2$ solution. The latter reagent gives a test for sulphates. What has happened to the lime-sulphur exposed to the air?

EXPERIMENT 125

Object:—To prepare an oil emulsion or miscible oil.

Apparatus and Materials:—Fish oil. (Sperm oil will do.) Potassium hydroxide solution of 40% strength, kerosene and paraffine oil.

Procedure:—Add 10 c.c. of oil to 15 c.c.. of KOH solution and heat to 300°F. with stirring. Extinguish the flame and stir in about 5 c.c. of kerosene oil. The product is the soap solution. When this is cool mix it thoroughly with ten times its volume of paraffine oil. Dilute it to 4.5 liters with water, stirring vigorously.

Results:—The product is the diluted miscible oil ready for use. How does it differ from the oil merely diluted with water to an equal volume? Why is the term "miscible" used?

EXPERIMENT 126

Object:—To prepare Bordeaux mixture.

Apparatus and Materials:—Pulverized quicklime, pulverized copper-sulphate, several beakers of 200 to 500 c.c. capacity and two small cylinders or tall jars.

Procedure:—Prepare a solution of 0.65 gram copper sulphate in 400 c.c. of water and divide into two equal parts. Prepare two solutions of quicklime each containing 0.25 gram of lime in 200 c.c. of water. Heat one of the solutions of lime nearly to boiling and pour it into one of the solutions of copper sulphate pour the other two solutions together into a large beaker at the same time. Now stir the two preparations of Bordeaux mixture and pour them into separate tall jars or cylinders.

Results:—In which preparation does the precipitate settle more slowly? This is the correctly prepared mixture. The copper should be in insoluble combination with lime and sulphuric acid, as soluble copper will poison the host plants as well as the parasitic fungi.

Test a dilute solution of copper sulphate with blue litmus paper. Now test your Bordeaux mixture in the same way. Is it acid in reaction? If so, how would you precipitate the remaining copper sulphate and make it weakly alkaline?

APPENDIX

Books and Bulletins Which Supplement This Textbook.

Chapters I—V—

Descriptive Chemistry. Newell. D. C. Heath & Co., Boston.
Experimental Chemistry. Newell. D. C. Heath & Co.
College Chemistry. Remsen. Henry Holt & Co., New York.
General Chemistry. Smith. The Century Co., New York.
Organic Chemistry. Noyes. W. A. Henry Holt & Co.

Chapter VI—

The Living Plant. Ganong. Henry Holt & Co., New York.
Plant Physiology. Duggar. The Macmillan Co., New York.
How Plants Grow. Johnson. Orange Judd Co., New York.

Chapter VII—

The Soil. King. The Macmillan Co.
Soils and Soil Fertility. Whitson & Walster. The Webb Pub. Co., St. Paul.
First Principles of Soil Fertilitv. Vivian. Orange Judd Co.
Soils. Lyon, Fippin & Buckman. The Macmillan Co.

Chapter VIII—

Manures and Fertilizers. Wheeler. The Macmillan Co.
Soils and Fertilizers. Snyder. The Macmillan Co.
Fertilizers and Crops. Van Slyke. Orange Judd Co.

Chapter IX—

Manures and Fertilizers. Wheeler. The Macmillan Co.
Farm Manure. Thorne. Orange Judd Co.
Barnyard Manure. Beal. Farmers' Bulletin 192, U. S. Dept. Agr., Washington, D. C.

Chapter X—

The Feeding of Animals. Jordan. The Macmillan Co.
Feeds and Feeding. Henry & Morrison. The Authors. Madison, Wis.

Chapter XI—

Elementary Treatise on Stock Feeds and Feeding. Halligan. The Chemical Publishing Co., Easton, Pa.

The Principles of Horse Feeding. Langworthy. Farmer's Bulletin 170.
The Computations of Rations for Farm Animals by the Use of Energy Values. Armsby. Farmers' Bulletin 346.

Chapter XII—

Dairy Chemistry. Snyder. The Macmillan Co.
Milk and Its Products, Wing. The Macmillan Co.
Household Tests for Oleomargarine and Renovated Butter. Patrick. Farmers' Bulletin 131.

Chapter XIII—

The Principles of Human Nutrition. Jordan. The Macmillan Co.
Food Products. Sherman. The Macmillan Co.
Human Food. Snyder. The Macmillan Co.
The Function and Uses of Food. Langworthy, Circular 46 (revised), Office of Experiment Stations, Washington, D. C.
Food Customs and Diet in American Homes. Langworthy, Circular 110, Office of Experiment Stations.
Beans, Peas, and Other Legumes as Food. Abel. Farmers' Bulletin 121.
Principles of Nutrition and Nutritive Value of Foods. Atwater. Farmers' Bulletin 142.
Cereal Breakfast Foods. Woods and Snyder, Farmers' Bulletin 249.
Nuts and Their Uses as Food. Jaffa, Farmers' Bulletin 332.
Bread and Bread Making. Atwater, Farmers' Bulletin 389.
Cheese and Its Economical Use in the Diet. Langworthy and Hunt. Farmers' Bulletin 487.
Canning Tomatoes at Home and in Club Work. Breazeale and Benson. Farmers Bulletin 521.

Chapter XIV—

Textile Fibers. Matthews. Wiley and Sons, New York.
Dyes and Dyeing. Pellew. McBride, Nast & Co., New York.
The Chemistry of Cooking and Cleaning. Richards and Elliott. Home Science Pub. Co., Boston, Mass.
The Chemistry and Testing of Cement. Desch. Edwin Arnold, London, England.
The Spraying of Plants. Lodeman. The Macmillan Co.
Important Insecticides. Marlatt. Farmers' Bulletin 127.
Fungicides. Waite. Farmers' Bulletin 243.
Some Common Disinfectants. Dorset. Farmers' Bulletin 345.
Practical Methods of Disinfecting Stables. Pope. Farmers' Bulletin 480.

Composition of Soils of Different Types.

Type of Soil	Soluble in hot 23% HCl							Total		Approximate Weight per Cubic Foot
	Total Matter	Potassium	Calcium	Magnesium	Iron	Phosphorus	Sulphur	Nitrogen	Humus	
	%	%	%	%	%	%	%	%	%	Pounds
A sandy soil	5.35	0.13	0.34	0.14	0.85	0.06	0.04	0.04	0.47	100
A clayey soil	52.36	0.45	1.74	1.12	2.92	0.17	0.04	0.38	5.34	73
A peaty soil	81.53	0.27	0.36	0.06	1.82	0.14	0.01	0.62	15.00	45
A virgin prairie soil	27.70	0.37	0.49	0.23	2.04	0.15	0.02	0.38	5.12	65
A cotton raising soil	6.39	0.04	0.02	0.02	0.28	0.01	trace	0.05	0.70	90
A fruit raising soil	27.28	0.56	0.82	0.78	6.50	0.05	0.03	0.20	1.09	83
An average fertile soil	20.05	0.24	1.55	0.33	1.87	0.10	0.01	0.29	2.35	85

Average Composition of Fresh Manures.

Animal	Water %	Nitrogen %	Phosphorus %	Potassium %
Cow	77.0	0.44	0.07	0.33
Hen	57.5	1.27	0.36	0.23
Horse	70.0	0.58	0.12	0.44
Pig	73.0	0.45	0.08	0.50
Sheep	64.0	0.83	0.10	0.56
Mixed farm manure	75.9	0.45	0.09	0.43

Digestibility of Feeding Stuffs.

Feeding Stuff	Animal	Coefficient of Digestion				
		Ash %	Protein %	Crude Fiber %	Nitrogen Free Extract %	Fat %
Cornmeal	Ruminant	....	67.9	....	94.6	92.1
	Horse	....	75.6	....	95.7	73.1
	Pig	....	86.1	29.4	94.2	81.7
Clover hay	Ruminant	29.1	58.0	54.2	64.4	55.2
	Horse	....	56.0	37.0	63.0	29.0
Potatoes	Ruminant	....	44.7	....	90.4	13.0
	Horse	....	88.0	....	99.0	....
	Pig	44.6	84.5	....	98.1	....
Timothy hay	Ruminant	32.8	46.9	52.5	62.3	52.2
	Horse	34.0	21.2	42.6	47.3	47.3
Wheat bran	Ruminant	....	77.8	28.6	69.4	68.0
	Pig	....	75.1	33.0	65.5	71.8

Feeding Standards for Some Animals.

Daily Ration for 1000 lbs. Weight

Kind of Animal	Total Dry Matter Lbs.	Digestible Organic Matter			Nutritive Ratio
		Protein Lbs.	Carbohydrates Lbs.	Fat Lbs.	
Horse–Light work	20	1.5	9.5	0.4	1:7
Heavy work	26	2.5	13.3	0.8	1:6
Milch cow–Daily milk yield 11 lbs.	25	1.6	10.0	0.3	1:6.7
Milch cow–Daily milk yield. 22 lbs.	29	2.5	13.0	0.5	1:5.7
Sheep–Fine wooled	23	1.5	12.0	0.3	1:8.5
Fattening early	30	3.0	15.0	0.5	1:5.4
Fattening late	28	3.5	14.5	0.6	1:4.5
Growing Beef Cattle					
Age (mos.) Weight (lbs.)					
2 to 3 165	23	4.2	13.0	2.0	1:4.2
6 to 12 550	25	2.5	13.2	0.7	1:6.0
18 to 24 935	24	1.8	12.0	0.4	1:7.2

Composition and Fertility Content of Feeding Stuffs.

Feeding Stuff	Water %	Ash %	Protein %	Crude fiber %	Nitrogen—Free Extract %	Fat %	Fertility Content		
							Nitrogen %	Phosphorus %	Potassium %
Alfalfa hay	8.4	7.4	14.3	25.0	42.7	2.2	2.15	0.22	1.35
Barley grain	10.9	2.4	12.4	2.7	69.8	1.8	1.55	0.35	0.42
Barley straw	....	....	....	....	....	....	1.31	0.13	1.73
Brewer's grains	8.2	3.6	19.9	11.0	51.7	5.6	3.00	0.56	1.30
Corn grains	10.9	1.5	10.5	2.1	69.6	5.4	1.82	0.31	0.33
Corn silage	79.1	1.4	1.7	6.0	11.0	0.8	0.28	0.05	0.30
Corn stover	40.5	3.4	3.8	19.7	31.5	1.1	0.68	0.08	0.76
Clover hay (red)	15.3	6.2	12.3	34.8	38.1	3.3	1.98	0.16	1.74
Cotton seed meal	6.8	6.2	45.6	5.4	25.2	10.8	6.87	1.21	1.53
Gluten feed	7.8	1.1	24.0	5.3	51.2	10.6	5.65	0.78	1.13
Linseed meal	10.0	5.2	36.1	8.4	36.7	3.6	5.65	0.78	1.13
Oat grain	11.0	3.0	11.8	9.5	59.7	5.0	2.24	0.39	0.56
Oat straw	9.2	5.1	4.0	37.0	42.4	2.3	0.62	0.09	1.03
Potato	78.9	1.0	2.1	0.6	17.3	0.1	0.22	0.03	0.25
Rutabaga	88.6	1.2	1.2	1.3	7.5	0.2	0.20	0.05	0.40
Sugar beet	86.5	0.9	1.8	0.9	9.8	0.1	0.22	0.04	0.40
Timothy hay	13.2	4.4	5.9	29.0	45.0	2.5	1.18	0.22	1.48
Wheat grain	10.5	1.8	11.8	1.8	72.0	2.1	2.48	0.41	0.53
Wheat bran	11.9	5.8	15.4	9.0	53.9	4.0	2.67	1.26	1.34
Wheat straw	9.6	4.2	3.4	38.1	43.4	1.3	0.61	0.05	0.44

Production Values of a Few Feeding Stuffs per 100 Pounds.

Feeding Stuff	Total Dry Matter Lbs.	Total Crude Fiber Lbs.	Digestible			Production Value Therms
			Protein Lbs.	Carbohydrates Lbs.	Fat Lbs.	
Corn grain..........	89.1	2.1	6.79	66.12	4.97	88.84
Corn silage..........	25.6	5.8	1.21	14.56	0.88	14.26
Clover hay..........	84.7	24.8	5.41	38.15	1.81	34.74
Gluten feed..........	91.9	6.4	19.95	54.22	5.35	79.32
Linseed meal........	90.1	8.8	29.26	38.72	2.90	74.67
Oat grain...........	89.0	9.5	8.36	48.34	4.18	66.27
Mangel.............	9.1	0.8	0.14	5.65	0.11	4.62
Timothy hay........	86.8	29.6	2.05	43.72	1.43	33.56
Wheat bran.........	88.1	9.0	10.21	41.23	2.87	48.23
Wheat straw........	90.4	38.1	0.37	38.30	0.40	16.56

Factors for Converting Metric into Ordinary Units

1 inch = 2.54 cm. 1 cm. = 0.3937 inches. For practical purposes it is sufficient to remember that about 2½ cm. = 1 inch.

A liter is the volume of a cube whose side is 10 cm. Therefore,

1 liter = 1,000 cubic centimeters;
1 pint = 0.5679 liter;
1 gallon = 4.54346 liters;
1 liter = 0.2201 gallon.

The gram is the weight of 1 c. c. of pure water at 4°C.

1 liter of pure water at 4° = 1 kilo (1,000 grams).

1 oz. = 28.35 gms. 1 gram = 15.432 grains.
1 lb. = 453.6 gms. 1 kilo = 2.2046 lbs.

Formulae for converting Fahrenheit Degrees into Centigrade, and the Reverse

$$C.^\circ = 5/9\,(F.^\circ - 32).$$
$$F.^\circ = 9/5C.^\circ + 32.$$

SIGNIFICANCE OF TERMINATIONS

In a compound composed of two kinds of elements, the names of both constituents are generally involved in the name of the compound. The name of the more electro-negative element (generally a non-metal) is usually placed last and has its termination changed to *ide;* oxygen forming oxides, chlorine, chlorides, etc. The name of the more electro-positive element (generally a metal) is usually placed first and is either used unchanged or its termination changed to *ous* or *ic*, according to its valence. *Ous* is employed for lower and *ic* for higher valencies. The compound SO_2 is called sulphurous oxide and SO_3 is called sulphuric oxide.

Prefixes are sometimes used as *di* in carbon dioxide, *tri* in phosphorous trioxide, etc. *Hypo* is used for lower valencies and *per* for higher, as Cl_2O, hypochlorous oxide, and Na_2O_2, sodium peroxide.

In naming salts containing three elements, usually only the names of two of the constituents are involved. The endings *ite* and *ate* are used in connection with the name of the non-metal, *ite* when the salt is formed from an *ous* acid and *ate* when formed from an *ic* acid. Ferrous sulphite from sulphurous acid and ferric sulphate from sulphuric acid.

Table of Atomic Weights

Name	Symbol	Value
Aluminium	Al	27.1
Antimony	Sb	120.0
Argon	A	39.88
Arsenic	As	74.96
Barium	Ba	137.37
Bismuth	Bi	208.0
Boron	B	11.0
Bromine	Br	79.920
Cadmium	Cd	112.40
Caesium	Cs	132.81
Calcium	Ca	40.07
Carbon	C	12.00
Cerium	Ce	140.25
Chlorine	Cl	35.46
Chromium	Cr	52.
Cobalt	Co	58.97
Columbium	Cb	93.5
Copper	Cu	63.67
Dysprosium	Dy	162.5
Erbium	Er	165.
Europium	Eu	152.0
Fluorine	F	19.0
Gadolinium	Gd	157.3
Gallium	Ga	69.9
Germanium	Ge	72.5
Glucinum	Gl	9.1
Gold	Au	197.2
Helium	He	3.99
Holmium	Ho	163.5
Hydrogen	H	1.008
Indium	In	114.8
Iodine	I	126.92
Iridium	Ir	193.1
Iron	Fe	55.84
Krypton	Kr	82.92
Lanthanum	La	139.0
Lead	Pb	207.10
Lithium	Li	6.94
Lutecium	Lu	174.0
Magnesium	Mg	24.32
Manganese	Mn	54.93
Mercury	Hg	200.6
Molybdenum	Mo	96.0
Neodymium	Nd	144.3
Neon	Ne	20.2
Nickel	Ni	58.68
Niton (radium emanation)	Nt	222.4
Osmium	Os	190.9
Oxygen	O	16.00
Palladium	Pd	106.07
Phosphorus	P	31.04
Platinum	Pt	195.2
Potassium	K	39.10
Praseodymium	Pr	140.6
Radium	Ra	226.4
Rhodium	Rh	102.9
Rubidium	Rb	85.45
Ruthenium	Ru	101.7
Samarium	Sa	150.4
Scandium	Sc	44.1
Selenium	Se	79.2
Silicon	Si	28.3
Silver	Ag	107.88
Sodium	Na	23.00
Strontium	Sr	87.63
Sulphur	S	32.07
Tantalum	Ta	181.5
Tellurium	Te	127.5
Terbium	Tb	159.2
Thallium	Ti	204.0
Thorium	Th	232.8
Thulium	Tm	168.5
Tin	Sn	119.0
Titanium	Ti	48.1
Tungsten	W	184.0
Uranium	U	238.5
Vanadium	V	51.0
Xenon	Xe	30.2
Ytterbium	Yb	172.0
Yttrium	Yt	89.0
Zinc	Zn	65.37
Zirconium	Zr	90.6

Chemicals Required for a Class of 10 Students

(Quantities stated in grams)

Acid, acetic (glacial)	400
arsenious	25
hydrochloric (sp. gr. 1.20)	2000
nitric (sp. gr. 1.42)	2000
sulphuric (sp. gr. 1.84)	2000
tartaric, powder	100
Acid phosphate (mono-calcium phosphate)	100
Ammonium hydroxide (sp. gr. 0.90)	2000
Ammonium carbonate	10
Ammonium chloride	100
Ammonium oxalate	25
Ammonium sulphate	100
Alcohol (ethyl) 95%	2000
Alum powder	50
Animal charcoal	100
Antimony powder	25
Barium chloride	50
Bleaching powder	200
Blood, dried	100
Bone ash	100
Bone meal, steamed	200
Borax powder	50
Calcium carbonate, chalk	200
limestone	200
marble	200
Calcium chloride	200
Calcium cyanamide	200
Calcium hydroxide (lime-water)	
Charcoal	100
Chloroform	50
Clay	50
Copper wire	200
Copper oxide	50
Copper sulphate	100
Cream of tartar	100
Ether	100
Floats (powd. rock phosphate)	200
Formalin (formaldehyde)	50
Fehling's solution, parts A and B, each	200
Ferric chloride	25
Ferrous sulphate	100
Fish oil	100
Gasoline	——
Gypsum	50
Iodine	25
Iron filings	100
Iron powder	200
Iron wire, stout	100
Iron sulphide	500
Kerosene	——
Lime (quicklime)	500
Lead foil	30
Lead acetate	50
Linseed oil	25
Litmus paper, blue and red, each 5 vials.	
Magnesium ribbon	10
Magnesia (calcined)	50
Manganese dioxide	200
Molasses	——
Molybdic acid	30
Olive oil	25
Paraffin oil	3000
Pepsin	25
Phenolphthalein	5
Picture wire	——
Pitch	——
Potassium bromide	30
chlorate	500
chloride	100
ferrocyanide	100
iodide	30
hydroxide	500
nitrate	200
sulphate	500
Sand (pure)	500
Silver nitrate	10
Soap, castile	100
Sodium, metal	10
bicarbonate	100
carbonate	100
chloride	500
hydroxide	500
nitrate	200
phosphate (di-sodium)	25
Solder	50
Sugar (sucrose)	1000
Sulphur (flowers)	200
Tankage	200
Tannin	10
Tin	30
Varnish	——
Vaseline	——
Zinc, granulated	500
Zinc, sheet	100

PREPARATION OF SPECIAL REAGENTS

Fehling's Solution

Part A. 6.928 grams pure copper sulphate crystals dissolved in water and made to 100 c.c.

Part B. 35. 6 grams of powdered sodium-potassium tartrate and 10 grams sodium hydroxide dissolved in water and made to 100 c.c.

For use, equal volumes of parts A and B are mixed.

Iodine Solution

5 grams iodine and 10 grams potassium iodide dissolved in 85 c.c. of water.

Ammonium Molybdate Solution

20 grams molybdic oxide dissolved in 29 c.c. strongest ammonium hydroxide and 54 c.c. water. Pour slowly and with stirring into 98 c.c. strongest nitric acid diluted with 230 c.c. water.

Phenolphthalein Solution for Indicator

Dissolve 1 gram of phenolphthalein in 100 c.c. of 95% alcohol.

Apparatus Needed for the Experiments.

General

1 Small hot air oven.
1 Box scales weighing to 1 kilogram.
1 Inexpensive balance weighing from 0.01 to 100 grams.
1 Six inch porcelain mortar and pestle.
1 Compound microscope.
1 Gallon battery jar.
1 Six inch funnel.
12 One liter and two liter wide mouthed bottles, or
12 One pint and one quart mason jars.
12 One pint to two quart tin dishes.
1 Medium sized grater.
Cheese cloth.
3 Iron crucibles, 50 c.c.
Several tin covers to serve as dishes for drying, etc.
1 1000 c.c. cylinder.
Assorted rubber stoppers (solid) and corks.
1 Set cork borers.
Small magnifying glass.
Magnet.
Pneumatic trough.
Blast lamp and bellows.
Files, triangular and round.
Wing top.
Assorted rubber tubing.
Thistle tubes.
Blowpipes.

Each Student

1 Bunsen burner and tubing
25 11 c.m. filter papers.
2 Porcelain dishes, 3 inch.
4 300 c.c. and 2 50 c.c. beakers.
12 Test tubes, 6 x ¾ inch.
1 Crucible tongs, 9 inch.
1 Test tube clamp.
1 Ring stand and rings.
2 Florence flasks, 500 c.c.
1 Wire gauze, four inch.
1 Burette clamp.
1 Cylinder, 100 c.c. (graduated).
1 Glass funnel, 2½ inch diameter.
1 Porcelain crucible, 1¾ in. diam.
1 Hard glass test tube, 8 in.
2 Wide mouth bottles, 250 c.c.
1 Watch glass, 3 in. diam.
1 Test tube brush.

INDEX

(References are to pages.)

AGRICULTURAL TEXT BOOKS
FOR
HIGH SCHOOLS

Published by

WEBB PUBLISHING CO., ST. PAUL, MINN.

This series of agricultural books, of which Agricultural Engineering is a representative, is planned especially for high schools in which agriculture is taught. The books constitute a complete four-year graded course in agriculture. Each book is complete in itself, and its scope is well within the limits of the course. They are written by men eminent in their line, and who are well known for their clear and concise presentation of facts. Each of the books listed below has suggestive subjects for discussion and demonstration at the close of each chapter. The series constitutes a complete, concise, and practical course that will meet the urgent needs of the modern agricultural high schools and of short courses in schools and colleges.

FIELD CROPS

By A. D. WILSON, Sup't of Farmers' Institutes and Extension, Minnesota College of Agriculture, and C. W. WARBURTON, Agronomist, U. S. Dep't of Agriculture.

544 pages, 162 illustrations, cloth, $1.50 net.

The aim of this book is to present the peculiarities of each of the various classes and varieties of farm crops, the handling of the soil, selections of seed, and general crop management. The book covers the cereals, including corn, wheat, oats, rye, barley, etc.; forage crops, including hay grasses, clover, alfalfa, cowpeas and other legumes; how to make good meadows and pastures, and the art of hay making, etc.; root crops; sugar crops; fiber crops, including cotton, flax, hemp; tobacco, potatoes, in fact every farm crop of any importance is discussed. The introductory chapters are devoted to the general classification of farm crops and their uses and relative importance, and reviews the subject of how plants grow. The concluding chapters discuss the theory and practice of crop rotation and weeds and their eradication. A list of the best supplementary reading, including farmers' bulletins, is given at the close of each chapter. The style is easy, subject matter well arranged and vital, and the book is of excellent mechanical makeup throughout.

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